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BOMB DAMAGE REPAIR PRECAST SLAB DESIGN

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study was made to evaluate various methods of rapid repair of bomb craters on runways using precast concrete slabs as structural elements. Primary focus was on optimum utilization of the concrete slabs when placed on debris backfill and on compacted select material backfill. Three primary repair concepts were studied: placement of slabs flush with the surrounding pavement and interlocked at the edges with concrete grout (Flush Slab Method); placement of slabs slightly below the surrounding pavement and surfaced with a 2-inch thick concrete cap

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20. ABSTRACT (Continued).

screeded flush with the old pavement (Submerged Slab Method); and placement of the slab flush with the old pavement with no-load transfer mechanism (German Method). Analyses were made of the various repair methods based on estimated time of repair and on expected structural response under aircraft loading. Time estimates were subdivided into time elements for the major repair tasks. Structural analyses were conducted with layered elastic and modified finite element computer codes. Repair methods evaluated as having most potential for development as standard procedures were those involving use of slabs submerged in a capped-concrete matrix. Analyses indicated that the other two methods offered less potential for future development. It was recommended that field tests be conducted to further evaluate all three methods.

Plans of tests were developed for testing of the submerged and flush slab methods in a small crater test and of the submerged slab method in a large crater test. The test plans are included as appendices.

PREFACE

This report was prepared by the U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Mississippi, under MIPR Number N-82-40 and JON 26212014, with the Air Force Engineering and Services Center, Engineering and Services Laboratory, Tyndall AFB, Florida.

This report documents work done between October 1981 and March 1983. Captain Richard M. Gibbs and 1st Lt James A. Kirkland, HQ AFESC/RDCR, were the Project Officers.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. BACKGROUND

Modern aircraft depending on high-quality airfield surfaces have made the airfield runway a vulnerable target. Interdiction of the runway has become an easier method of neutralizing aircraft than attacking hardened aircraft shelters. To counter this threat, the Air Force Civil Engineer must be capable of repairing bomb-damaged runways within given time constraints and compatible with tactical requirements. Research in the area of rapid runway repair (RRR) has been conducted by the Air Force for a number of years, and a large number of repair techniques and materials have been evaluated. Current guidance for bomb damage repairs is given in Air Force Regulation 93-2 (AFR 93-2) (Reference 1) and in the RRR interim planning guide published by the Air Force Engineering and Services Center (AFESC) (Reference 2). These documents provide several options for the rapid repair of large craters, i.e., those having an apparent diameter exceeding 15 feet. AFR 93-2 specifies initial backfilling of the crater with debris followed by 1 or 2 feet of compacted select aggregate and surfacing with a large patch made of AM-2 landing mat. The interim guidance document indicates that use of compacted well-graded crushed aggregate in the top 24 inches of the crater backfill will provide an adequate structural repair comparable to the AM-2 repair; however, a foreign object damage (FOD) cover is required for the crushed aggregate repair. In recent studies a fiberglass-reinforced polyester FOD cover has been found to be highly effective and even offers some rutting resistance to aircraft traffic loadings.

Although both the AM-2 repair and the crushed aggregate repair have been found to be very satisfactory from a structural standpoint, both methods require that considerable amounts of fill aggregate be stockpiled near the anticipated repair area. In addition, the construction effort required to transport the material and place and compact it in the crater is highly time-consuming.

Another undesirable characteristic, particularly with the AM-2 repair, evolves from the surface roughness problem. Since the AM-2 patch is placed on the existing pavement surface, this method inherently results in an elevated repair that could have an adverse effect on aircraft ground operations. The crushed aggregate repair with FOD cover also presents potential surface roughness problems. The FOD cover attached to the surface of the existing pavement causes some minor unevenness. In addition, it is somewhat difficult to screed the surface of the crushed aggregate repair to a smooth finish, and any unevenness is reflected in the surface of the flexible FOD cover.

The AFESC, in a continuing effort to develop new and improved techniques and methods of bomb damage repair, has conducted a number of field tests using precast concrete slabs as structural elements (Reference 3).

Used in conjunction with fast-setting cement grouts or concrete, these repair methods appear to offer high potential for improvements in repair time, load-carrying capacity, and finished repair surface smoothness. One obvious

advantage of the use of precast slabs is that by their sheer bulk or volume they occupy substantial space within the repair region. In addition, since such elements may actually be categorized as prefabricated paving blocks, it appears that placement of these units directly on pushback or improved debris fill may produce a repair of adequate structural or load-carrying capacity. Additionally, if rapid and accurate placement of the slabs can be achieved, this technique could satisfactorily replace current methods.

The U. S. Air Force Europe (USAFE) (Reference 4)* and the German Defense Ministry (GDM)** have evaluated the use of commercially available (in Europe) precast concrete slabs for rapid repair of bomb craters. Both USAFE and GDM have indicated favorable repair time with this method, and the Air Force is considering this technique for future applications.

Therefore, based on favorable results from the AFESC field tests with precast slabs and the European experience, this study was undertaken to evaluate various precast slab repair methods and to develop recommendations for future field testing by AFESC.

B. OBJECTIVES

The objectives of this study were:

to review various methods of rapid bomb crater repair utilizing precast portland cement concrete slabs;

to propose for field testing two or three of the methods that appear most promising, with respect to minimization of expenditures of time, manpower, and materials, and

to develop a general test plan which will include recommended slab and repair crater geometry, structural design, slab fabrication and crater backfill material, and equipment and manpower estimates for each of the methods proposed for field testing.

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* Telephone conversation between W. N. Brabston, U. S. Army Engineer Waterways Experiment Station, and Lt Col Dick Bergholz, USAFE, 2 April 1982.

** Presentation at 26th US/GE Logistics Staff Talks, 1-4 June 1981, Fuerstenfeld Bruch, FRG.

SECTION II

CONVENTIONAL USE AND CRATER REPAIR TESTS

A. PRECAST SLABS IN CONVENTIONAL PAVEMENTS

The use of precast concrete slabs in conventional road and airfield pavements is not a recent innovation, and extension of the technology to bomb crater repair has been investigated. A summary of precast slab use in several of the more prominent American and foreign projects has been well documented by Rollings and Chou (Reference 5).

In 1968, the South Dakota Department of Highways built a 900-foot long test section on U. S. Highway 14 using slabs that were 6 feet wide, 24 feet long, and 4 1/2 inches thick. The slabs were prestressed, and a grouted key configuration on the longitudinal sides provided load transfer.

The Michigan Highway Department developed a standard design for eight configurations of reinforced precast concrete slabs for use in pavement repair. The slabs were 12 feet long, varied from 6 to 12 feet wide (in 2-foot increments), and were 8 or 9 inches thick. Apparently only single slabs were used in each repair, and load transfer between the existing pavement and the repair slab was effected by using dowel bars inserted into the existing pavement and welded to plates cast in the repair slab.

In 1956, the U. S. Army Ohio River Division Laboratory developed a precast prestressed slab designed to prevent soil erosion and enhance dust abatement from missile backblast. The concrete for the beams incorporated lightweight aggregate and high early strength cement which reached a 28-day compressive strength of 5800 pounds per square inch (psi). The individual slabs were 1 foot wide and 18 feet long. The slabs had a basic thickness of 2 3/4 inches with 1-foot-wide transverse tee-sections 5 1/2 inches thick and on 2-foot centers for the length of the beam. These slabs were subjected to moving wheel loads varying from 5,800 to 24,000 pounds. Spalling and structural failures occurred under the 24,000-pound wheel loadings.

In airfield repairs, 116 damaged concrete slabs were replaced with precast slabs at San Diego's Lindbergh Field. Each slab was formed to match the existing slab, and specially designed patented load transfer devices were used to connect slabs.

Precast prestressed concrete slabs, 3.3 feet square and 6.3 inches thick, were used at Orly Airport in Paris. Although structurally adequate, the surface of the precast slab pavement was noticeably rough.

In Fenningly, England, and at Melsbrook in Brussels, precast slabs were used for airport construction. The Fenningly slabs were 30 feet by 9 feet and 6 inches thick. Those used at Melsbrook were 4.1 feet by 39 feet and 3 inches thick. In both cases the slabs were prestressed.

At a project in Japan, six experimental precast,prestressed concrete slabs were designed for DC-8 traffic. The slabs were 3.2 feet long, 7.5 feet wide,

and 7.9 inches thick. Load transfer was accomplished by means of a curved bar which was grouted in matched openings on adjacent slabs.

In the Soviet Union the precast concrete industry is extensively developed, and use of such slabs in airfield construction is an acceptable practice. Precast slabs are used both in new construction and in repair work. Biaxially prestressed slabs are preferred for pavements subject to heavy aircraft loads; however, axially stressed, conventionally reinforced and unreinforced slabs are also used in road and light-load airfield construction. Most airfield slabs are slightly over 6 feet wide and vary in length from 13 to 20 feet. Generally, length/width ratios are 2.0 or 3.0. Load transfer may or may not be used. Methods of load transfer include welded brackets and epoxy- or grout-filled joints.

B. AFESC TESTS

The AFESC has conducted several crater repair tests using polymer concrete. In two such tests precast concrete slabs were incorporated into the repair, and, in another test, polymer concrete alone was used. Descriptions of these tests, which have been summarized by Beyer and Bretz (mentioned previously in Reference 3), are given below. Each test is identified by an item number.

Item 10 - The objective of this test was to evaluate precast concrete slabs placed at grade and bonded together at the sides with a polymer concrete formulated by researchers at the University of Texas. The test was conducted in a 20-foot by 20-foot pit having a clay subgrade with a strength of 4 CBR. A 6-inch thick layer of compacted crushed limestone was placed over the clay, and a 3-inch thick sand leveling course was placed over the crushed limestone. Nine precast plain concrete slabs, each 6 feet by 6 feet by 12 inches thick, were then positioned in the repair opening. The surface of the sand was leveled so that, after placement, the top surface of each slab was flush with the surrounding pavement. The sides of the slabs were cast with keyway faces to facilitate interlock and load transfer. Spacing between individual slabs and around the perimeter of the repair opening was about 6 inches (see Figure 1).

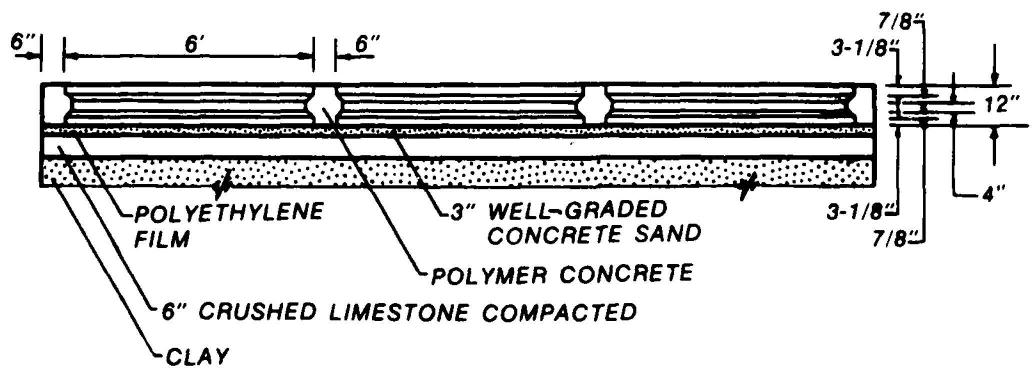

Figure 1. Cross Section of Test Pit, Item 10.

Next, polymer concrete was placed into void spaces up to the surface of the slabs and was trowelled to a smooth finish. After the polymer concrete had cured (about 2 hours), test traffic was applied with F-4 and C-141 test carts. The F-4 test cart has a single wheel with a 27,000-pound wheel load and 265-psi tire inflation pressure. The C-141 test cart has four wheels with a 141,000-pound gross load and 185-psi tire inflation pressure. The test area was subjected to 150 coverages of F-4 load cart traffic and 70 coverages of C-141 load cart traffic with no visible signs of deterioration.

Item 11 - This test was also designed to evaluate the use of precast slabs and was conducted in a 20-foot by 20-foot pit. The clay subgrade had a strength of 4 CBR, and 6 inches of compacted crushed limestone was placed over the clay. Very thin sand courses and polyethylene film were also used. Nine precast plain concrete slabs, each 6 feet by 6 feet and 8 inches thick, were used. These slabs were also cast with concave keyway sides. Elevation of the sand surface was such that, after placement, the slab surfaces were about 2 inches below the surface of the surrounding pavement. Thus, when placed, the polymer concrete formed a 2-inch thick structural cap over the slabs. When screeded and trowelled, the cap formed a smooth repair surface flush with the surrounding pavement (see Figure 2). Three types of polymer concrete were used: Crylon®, Silikal®, and the University of Texas formulation. After the test repair had been completed and the polymer concrete cured, test traffic was applied with the F-4 and C-141 test carts previously described. After trafficking, profile data revealed little change in surface elevation.

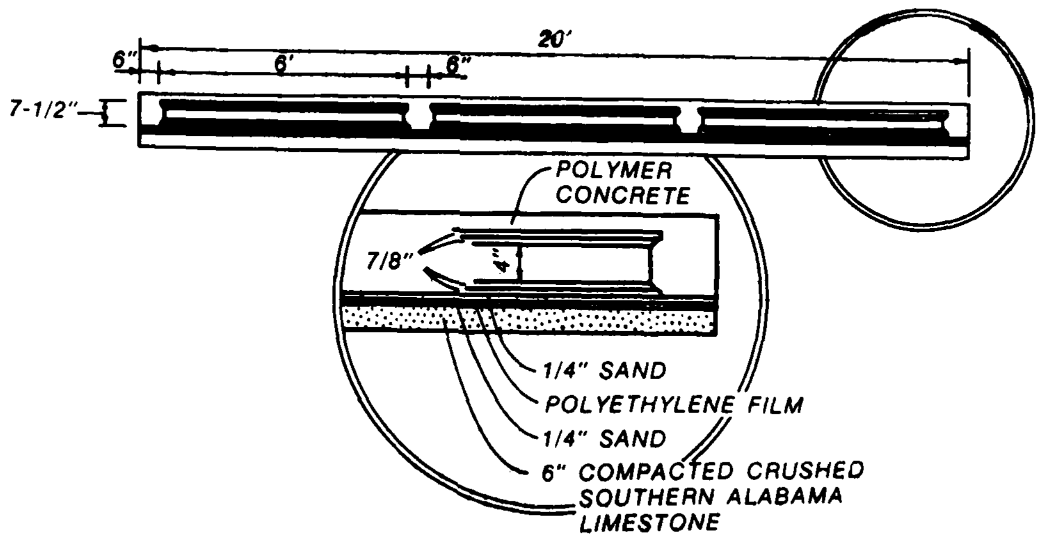

Figure 2. Cross Section of Test Pit, Item 11.

Item 12 - The objective of this test was to evaluate the performance of the University of Texas polymer concrete when used as a structural layer directly on a clay subgrade. The test was conducted in a 20-foot by 20-foot pit; however, two different thicknesses of polymer concrete were evaluated, and each was placed on a clay subgrade of different strength. Therefore, and

slab had horizontal dimensions of 20 feet long and 10 feet wide. One slab was 8 inches thick and placed on a subgrade having a strength of 6 CBR. The other slab was 5 inches thick and placed on a subgrade having a strength of 6 CBR (see Figure 3). Test traffic was applied with F-4 and C-141 load carts. After

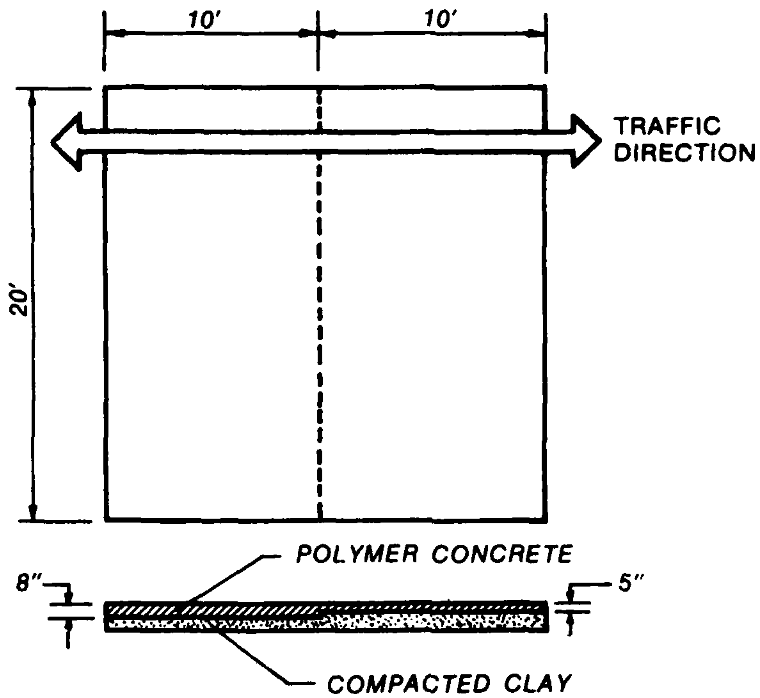

Figure 3. Test Configuration, Item 12.

150 coverages of the former vehicle and 70 coverages of the latter, examination of surface profile data revealed no significant changes in elevation. Additional traffic was later applied to evaluate the performance of the 5-inch slab which had indicated localized cracking. After 60 additional coverages of the F-4 load cart and 20 coverages of the C-141 load cart, there was little additional differential slab movement, and the slab was not considered failed.

C. GERMAN SLAB TESTS

Crater repair tests have been conducted by both the German Defense Ministry (GDM) and the USAFE using commercially available 2-meter* by 2-meter precast reinforced concrete slabs. Slab thicknesses of 12 to 15 centimeters** have been reported. The slabs used by the GDM are 12 centimeters thick, as are

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* Meters can be converted to feet by multiplying by a factor of 3.280839.

** Centimeters can be converted to feet by multiplying by a factor of 0.03280839, or to inches by multiplying by 0.3937007.

those advertised commercially in German literature.* In these tests, the prepared crater openings have generally been approximately 6 meters by 6 meters for the GDM tests and 8 meters by 8 meters for the USAFE tests. In both cases, after the crater has been prepared, a fine aggregate leveling course is placed and screeded for placement and seating of the slabs. A special quick lift/release device attached to a forklift is used in slab transportation and placement. There is no load transfer between adjacent slabs. Slab placement time has been observed at 42 minutes for 16 slabs. No application of test traffic on the completed repair has been reported.

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* Such advertisements can be found in the pamphlet by Commercial Literature Stelcon, Inc., Stelcon House, Alfred Strasse 98, Essen, Federal Republic of Germany.

SECTION III

ANALYSIS AND EVALUATION OF TEST CONCEPTS

A. GENERAL

The various types of bomb damage repair methods may be analyzed with respect to two general areas: time of repair and structural adequacy of the repair to withstand aircraft loadings. The time required to complete a crater repair depends on size of the basic crater, size of the repair area, and availability of resources: manpower, equipment, and materials. The structural adequacy of a completed repair depends on the type and characteristics of the backfill material and of the overlying structural or pavement layer. For this study, the predominant characteristic of the various repair methods considered is the inclusion of precast concrete slabs in the paving layer; however, a number of repair configurations are addressed to include various combinations of pavement layers and backfill materials. In order to establish a basis for study and analysis of bomb damage repair methods, information obtained from past AFESC tests involving field tests on 20-foot by 20-foot craters and from the 6-meter by 6-meter German repair method were evaluated. These data, along with other information from actual and hypothetical crater repairs, were used to develop estimates of repair times and resource requirements for other 20-foot by 20-foot repairs and for extrapolation to repair estimates for 50-foot by 50-foot repairs.

B. TIME ANALYSIS

1. Approach and Assumptions

Time estimates were developed for six repair configurations in a 20-foot by 20-foot area and six additional ones in a 50-foot by 50-foot area. A time estimate was also developed for repair of a 50-foot diameter crater for which the surface would simply be cut back to the undisturbed pavement resulting in an irregular opening. The time and repair schedule indicated for the German repair is based on actual observations of a field repair demonstration. Past experience in bomb crater repair tests has revealed shortcomings and inadequacies in techniques, materials, and equipment. Notable deficiencies exist in the areas of pavement cutting, preparation, and placement of rapid-setting and polymer concrete and screeding and leveling of backfill. In developing the time estimates it was felt that in order to achieve a suitable repair within acceptable time constraints; i.e. about 4 hours, these deficiencies will be overcome. Therefore, where necessary, production rates for certain task elements were assumed although they may not be state of the art and, as such, represent goals that must be accomplished to achieve target repair times. Significant production rates used were: concrete cutting or breaking rate of 2 linear feet per minute per pneumatic hammer, placement rate of polymer or rapid set concrete of 15 ft^3/min; and final screeding rate for soil and aggregate at 20 to 30 ft^2/min to achieve a satisfactory surface. Also, it was assumed that the precast slabs could be placed, aligned, and leveled to acceptable standards and that rapid set concrete could be adequately cured in a 1-hour period. Where past experience indicated achievable task element times, primarily on small crater repair,

these were incorporated into time estimates for other 20-foot by 20-foot repair schedules and extrapolated to the 50-foot by 50-foot repair schedules. In addition, repair estimates were based on availability of all necessary resources of manpower and equipment and not constrained to current PRIME BEEF and RED HORSE capabilities.

2. Polymer Cap on Debris (20-Foot by 20-Foot Repair)

As indicated in the project statement of work, the standard of comparison for time analysis is a repair consisting of an 8-inch thick polymer concrete structural cap placed directly on a debris backfill. Rate of placement of the polymer concrete was established at 15 ft^3/min. Based on a 20-foot by 20-foot repair area, a time analysis of this method indicates a total repair time of 120 minutes (see Figure 4 and Table 1). Of this total repair time, 60 minutes are required for curing the polymer concrete.

3. Submerged Slab Repair, Debris Fill (20-Foot by 20-Foot Repair)

This repair consists of placing nine 6-foot by 6-foot concrete slabs directly on debris backfill and a fine aggregate bedding course. The slab surfaces are about 2 inches below the surface of the surrounding pavement, and a polymer or rapid setting concrete cap is placed over the slabs to form a smooth finished surface. In this analysis it is assumed that there will be a requirement to place debris in the repair opening to form a foundation rather than simply place the slabs on a previously prepared bed. A critical element in this repair is time of placement of the slabs. Data from previous AFESC tests have indicated a time of placement of about 1 minute per slab. Observations of the German repair method have indicated placement time of about 2 1/2 minutes per slab. Therefore, for this analysis a placement rate of about 1 1/2 minutes per slab was assumed. This time analysis is indicated in Figure 5 and Table 2. From this analysis, a total repair time of 180 minutes is indicated.

4. Flush Slab Repair, Debris Fill (20-Foot by 20-Foot Repair)

This repair technique is similar to the submerged slab repair except that the slabs are placed so that the top surfaces are flush with the surrounding pavement and form the actual traffic surface. Rapid-setting concrete grout is placed between slabs to provide load transfer. Time analysis for this method indicates a total repair time of 195 minutes (see Figure 6 and Table 3). While there are significant differences between the individual task items of the submerged and flush slab repair methods, the net effect on total time of repair is not substantial. In the submerged slab repair method, leveling of the fine aggregate bedding material may be accomplished adequately with a dozer; however, in the flush slab method a special screeding device may be required for this task. Thus, in the flush slab method, a time element of 20 minutes is allowed for screeding. Another difference between the two methods is that in the submerged slab method the time allotted for placement of the slabs is 15 minutes; however, in the flush slab method the additional effort required to level each slab increases the time element to 30 minutes. Time elements allotted for placing the rapid-setting concrete grout for the submerged and flush slab methods are 20 and 10 minutes, respectively.

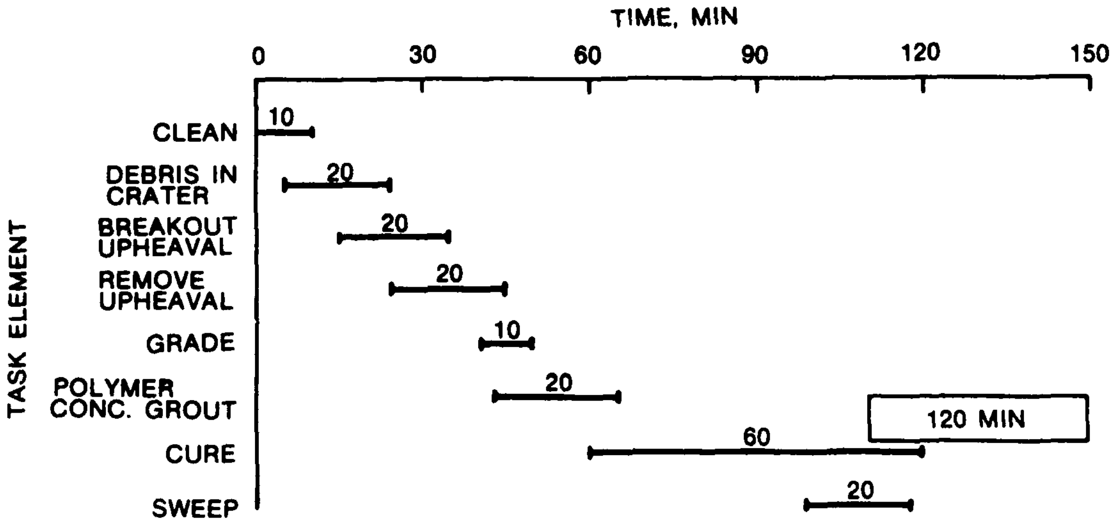

Figure 4. Time Analysis, 8-Inch Polymer Concrete Cap on Debris (20-Foot by 20-Foot Repair).

TABLE 1. TIME AND EQUIPMENT REQUIREMENTS, 8-INCH POLYMER CONCRETE CAP ON DEBRIS (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader/1 Grader/1 Dozer
Place Debris Backfill	20	1 Dozer
Breakout Upheaval	20	2 Pneumatic Hammers
Remove Upheaval	20	2 Excavators
Grade Backfill	10	1 Dozer
Place Polymer Concrete	20	2 Mobile Mixers
Cure Concrete	60	--
Sweep Repair Area	20	1 Sweeper

5. Submerged Slab Repair, Select Fill (20-Foot by 20-Foot Repair)

This repair method involves removing the main portion of the debris and backfill, and filling the crater with select fill material (see Figure 7 and Table 4). The estimated impact of using primarily select fill in the submerged slab method would be to increase the debris removal time from 20 to 30 minutes to obtain a clean crater and to decrease the total time from initiation of the filling activity to initiation of slab placement from 50 to 40 minutes. The decrease in fill time reflects the elimination of the requirement for placement of a fine-aggregate bedding course since the select material, being more uniform, could be leveled sufficiently to receive the pavement

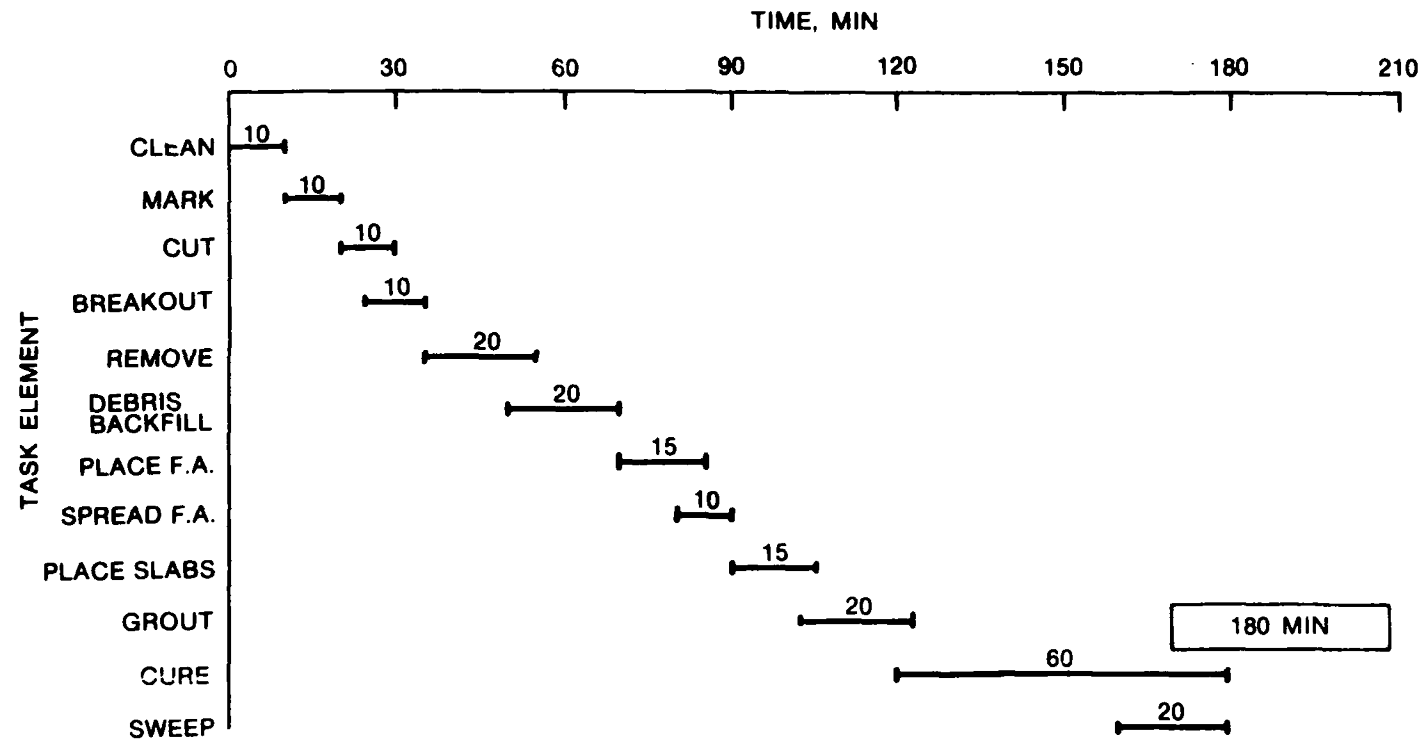

Figure 5. Time Analysis, Submerged Slab with Rapid-Set Concrete Debris Fill (20-Foot by 20-Foot Repair).

TABLE 2. TIME AND EQUIPMENT REQUIREMENTS, SUBMERGED SLAB WITH RAPID-SET CONCRETE CAP, DEBRIS FILL (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader/1 Grader/1 Dozer
Mark	10	Survey Equipment
Cut Concrete	10	2 Concrete Saws
Breakout Upheaval	10	2 Pneumatic Hammers
Remove Upheaval	20	2 Excavators
Place Debris Backfill	20	2 Dozers
Place Fine Aggregate	15	2 Trucks
Spread Fine Aggregate	10	1 Loader/1 Dozer
Place Slabs	15	2 Forklifts
Place Grout	20	2 Mobile Mixers
Cure Concrete	60	--
Sweep Repair Area	20	1 Sweeper

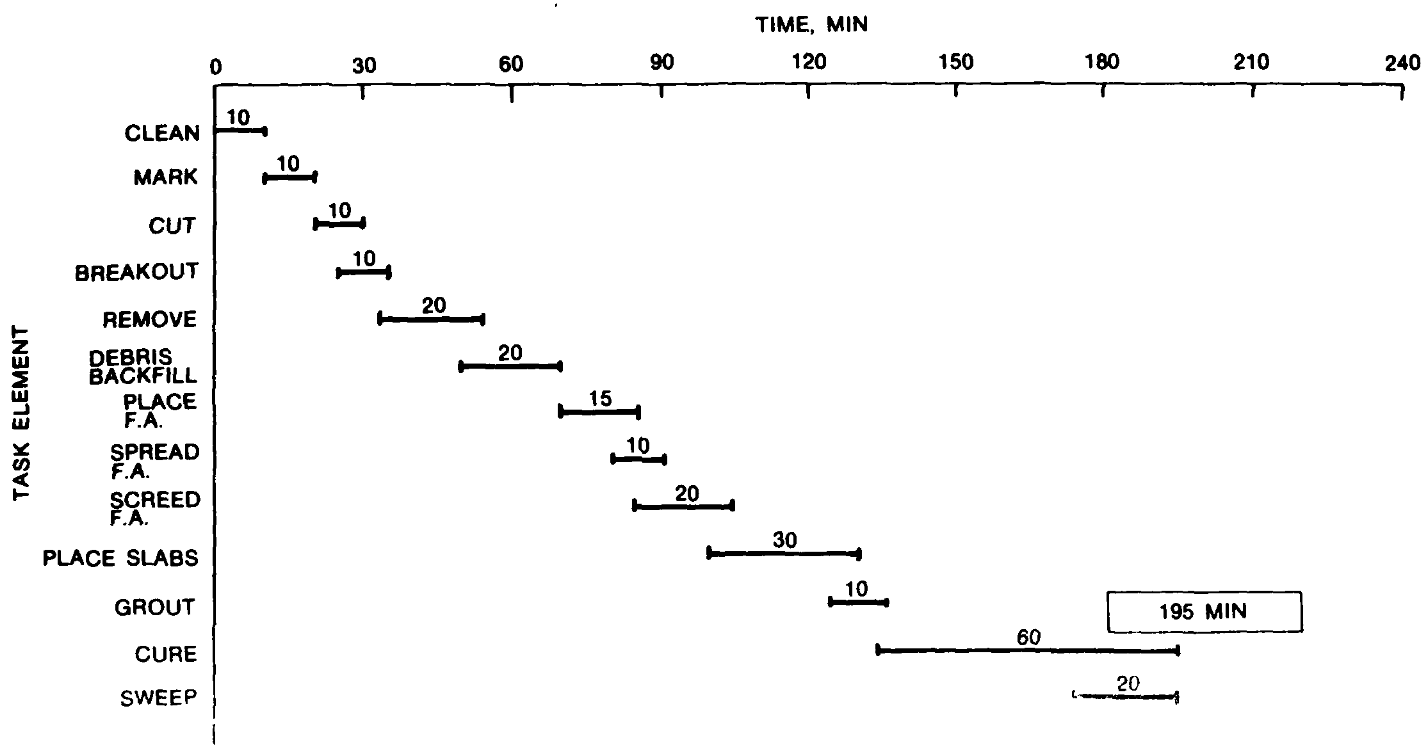

Figure 6. Time Analysis, Flush Slab with Rapid-Set Concrete, Debris Fill (20-Foot by 20-Foot Repair).

TABLE 3. TIME AND EQUIPMENT REQUIREMENTS, FLUSH SLAB WITH RAPID-SET CONCRETE, DEBRIS FILL (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clear Crater	10	1 Loader/1 Grader/1 Dozer
Mark	10	Survey Equipment
Cut Concrete	10	2 Concrete Saws
Breakout Upheaval	20	2 Pneumatic Hammers
Remove Upheaval	20	2 Excavators
Place Debris Backfill	20	2 Dozers
Place Fine Aggregate	15	2 Trucks
Spread Fine Aggregate	15	1 Loader/1 Dozer
Screed Fine Aggregate	20	1 Screed
Place Slabs	30	2 Forklifts
Place Grout	10	1 Mobile Mixer
Cure Concrete	60	--
Sweep Repair Area	20	1 Sweeper

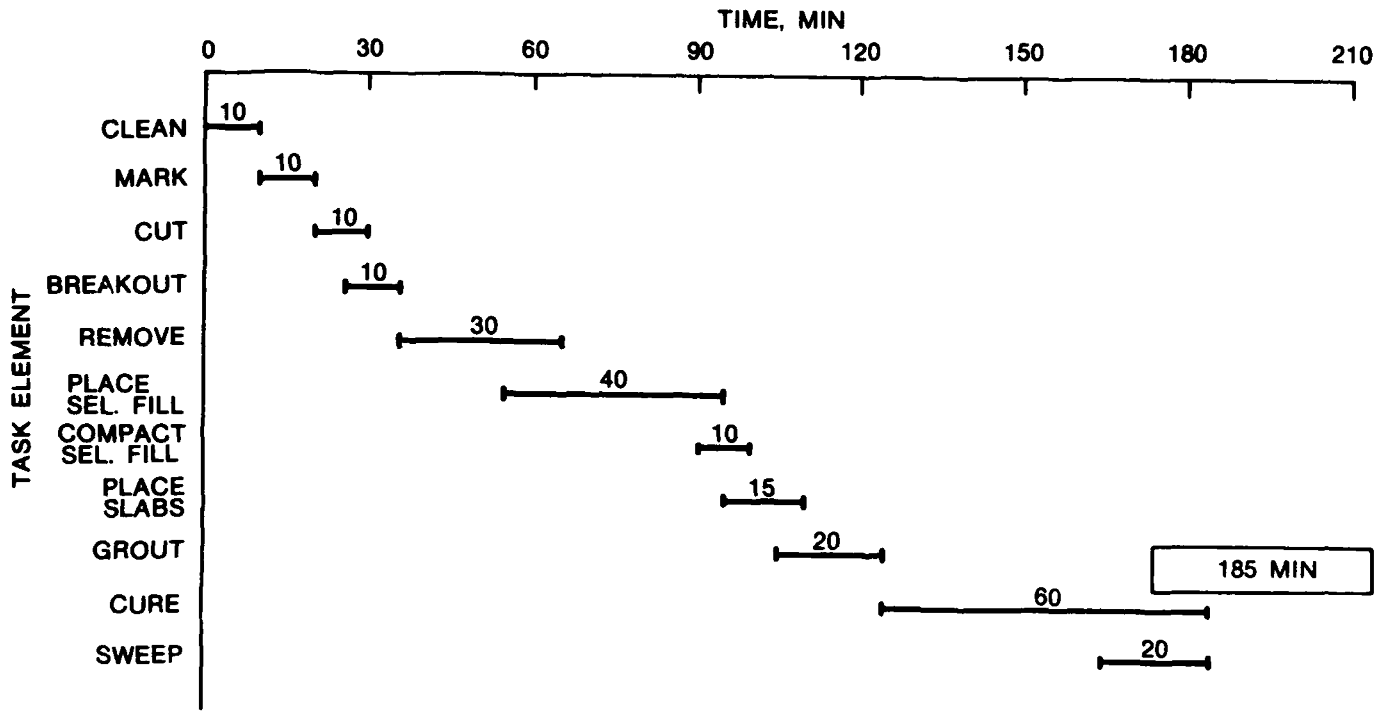

Figure 7. Time Analysis, Submerged Slab with Rapid-Set Concrete Cap, Select Fill (20-Foot by 20-Foot Repair).

TABLE 4. TIME EQUIPMENT REQUIREMENTS, SUBMERGED SLAB WITH RAPID-SET CONCRETE CAP, SELECT FILL (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader/1 Grader/1 Dozer
Mark	10	Survey Equipment
Cut Concrete	10	2 Concrete Saws
Breakout Upheaval	10	2 Pneumatic Hammers
Remove Upheaval	30	2 Excavators
Place Select Fill	40	2 Dump Trucks/2 Dozers
Compact Select Fill	10	1 Vibratory Roller
Place Slabs	15	2 Forklifts
Place Grout	20	1 Mobile Mixer
Cure Concrete	60	--
Sweep Repair Area	20	1 Sweeper

slab. Thus, the estimated net effect in using select fill in the submerged slab method would be a slight reduction in total repair time to 185 minutes.

6. Flush Slab Repair, Select Fill with Leveling Course (20-Foot by 20-Foot Repair).

Time element and equipment projections for this repair method are shown in Figure 8 and Table 5. The total estimated time of repair is 210 minutes, or 15 minutes more than the similar repair with debris backfill. Although additional time will be required for crater cleaning and placement and compaction of the select fill, this type of material can be graded and compacted sufficiently level to facilitate more rapid placement of a leveling course of aggregate, i.e., from 35 minutes to 25 minutes. Thus, the trade-off in time elements results in some increase in total time of repair.

7. Flush Slab Repair, Select Fill, No Leveling Course (20-Foot by 20-Foot Repair).

Time estimates and equipment data for this repair method are shown in Figure 9 and Table 6. This repair approach differs from the previous flush slab-select fill material in that it is assumed here that the select fill may be screeded, compacted, and leveled without requiring a special aggregate leveling course; thus, the slabs may be placed directly on the finished select fill with minimum leveling effort. The compaction and leveling time elements require a total of 20 minutes as compared to 35 minutes for similar tasks in the previous repair methods. The total estimated time of repair is 200 minutes.

8. German Repair Method

Time data for this repair method were obtained by AFESC personnel through direct observation of a repair demonstration and from literature prepared by the German Defense Ministry. The time analysis is based on placement of coarse and fine aggregate for the foundation and positioning of sixteen 2-meter by 2-meter slabs. No load transfer was provided between slabs. The observed total repair time was 147 minutes. The time analysis and equipment data are provided in Figure 10 and Table 7, respectively. Apparently, had debris backfill been used instead of aggregate, there would be little difference in time of repair. In fact, leveling of debris backfill may have had the result of increasing repair time.

9. Polymer Cap on Debris (50-Foot by 50-Foot Repair)

An estimated time analysis based on repairing the crater with an 8-inch-thick polymer concrete cap was done in order to provide baseline data for estimation of repair of a large crater. The time estimates for clearing the crater area, cutting the pavement, filling with debris backfill, and preparing the debris surface for placement of the polymer concrete were based on extrapolated data from the small crater repair time analysis, estimated task time requirements from other studies, estimated equipment capabilities, and other judgmental factors. For the large crater repair it was assumed that the apparent crater diameter is 30 feet, crater depth is approximately 10 feet, and the pavement is cut back to about 25 feet from the crater center in an approximate regular geometric configuration. Concrete-cutting rate was assumed at 10 linear feet per minute. It was also assumed that the optimum

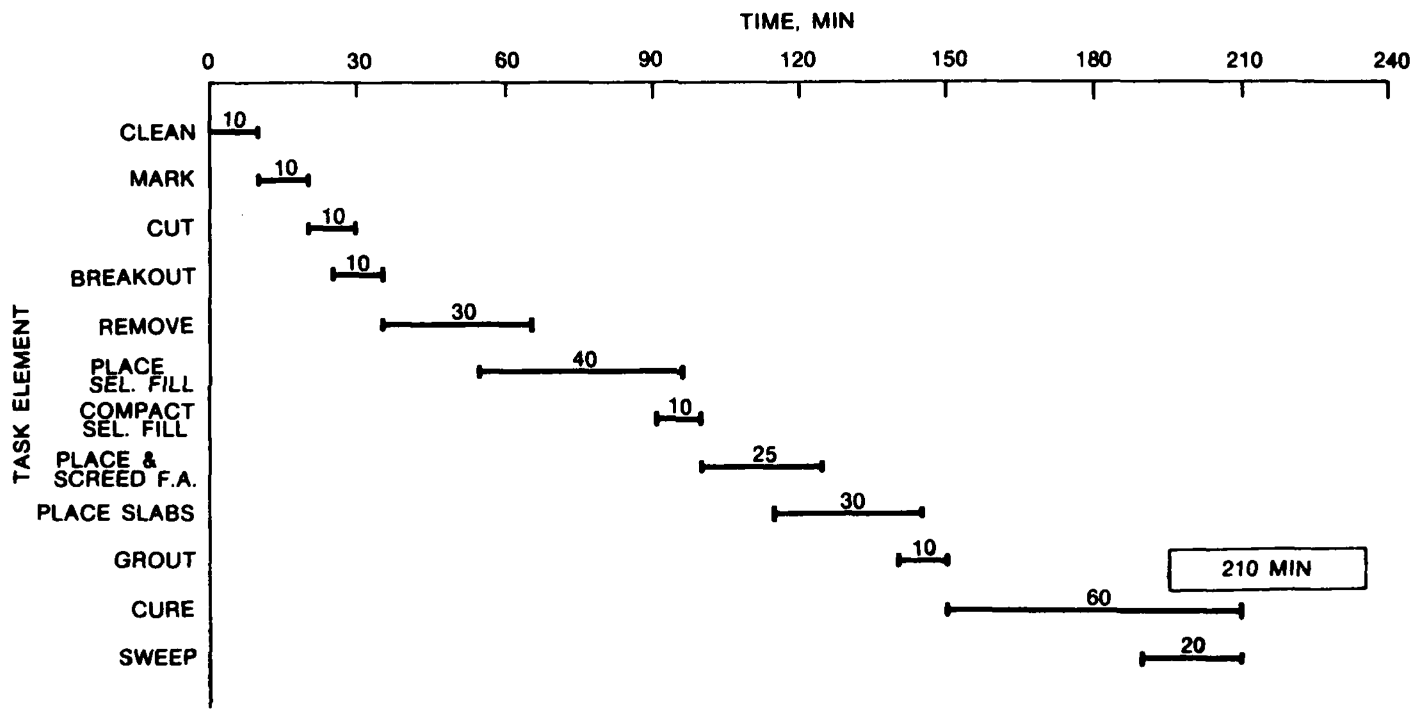

Figure 8. Time Analysis, Flush Slab with Rapid-Set Concrete, Select Fill and Leveling Course (20-Foot by 20-Foot Repair).

TABLE 5. TIME AND EQUIPMENT REQUIREMENTS, FLUSH SLAB WITH RAPID-SET CONCRETE, SELECT FILL AND LEVELING COURSE (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader/1 Grader/1 Dozer
Mark	10	Survey Equipment
Cut Concrete	10	2 Concrete Saws
Breakout Upheaval	10	2 Pneumatic Hammers
Remove Upheaval	30	2 Excavators
Place Select Fill	40	2 Dump Trucks/2 Dozers
Compact Select Fill	10	1 Vibratory Roller
Place and Screed Fine Aggregate	25	2 Trucks/1 Screed
Place Slabs	30	2 Forklifts
Place Concrete	20	1 Mobile Mixer
Cure Concrete	60	--
Sweep Repair Area	20	1 Sweeper

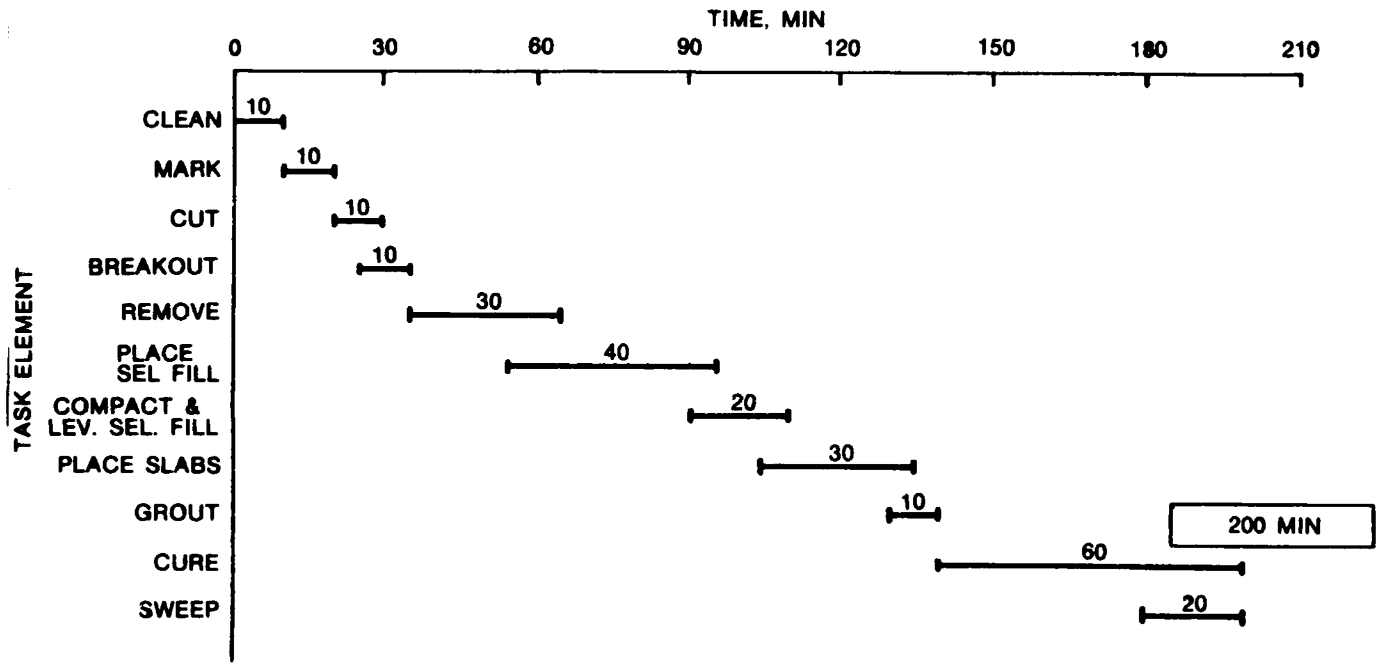

Figure 9. Time Analysis, Flush Slab with Rapid-Set Concrete, Select Fill, No Leveling Course (20-Foot by 20-Foot Repair).

TABLE 6. TIME AND EQUIPMENT REQUIREMENTS, FLUSH SLAB WITH RAPID-SET CONCRETE, SELECT FILL, NO LEVELING COURSE (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader/1 Grader/1 Dozer
Mark	10	Survey Equipment
Cut Concrete	10	2 Concrete Saws
Breakout Upheaval	10	2 Pneumatic Hammers
Remove Upheaval	30	2 Excavators
Place Select Fill	40	2 Dump Trucks/2 Dozers
Compact and Level Select Fill	20	1 Vibratory Roller
Place Slabs	30	2 Forklifts
Place Grout	10	1 Mobile Mixer
Cure Concrete	60	—
Sweep Repair Area	20	1 Sweeper

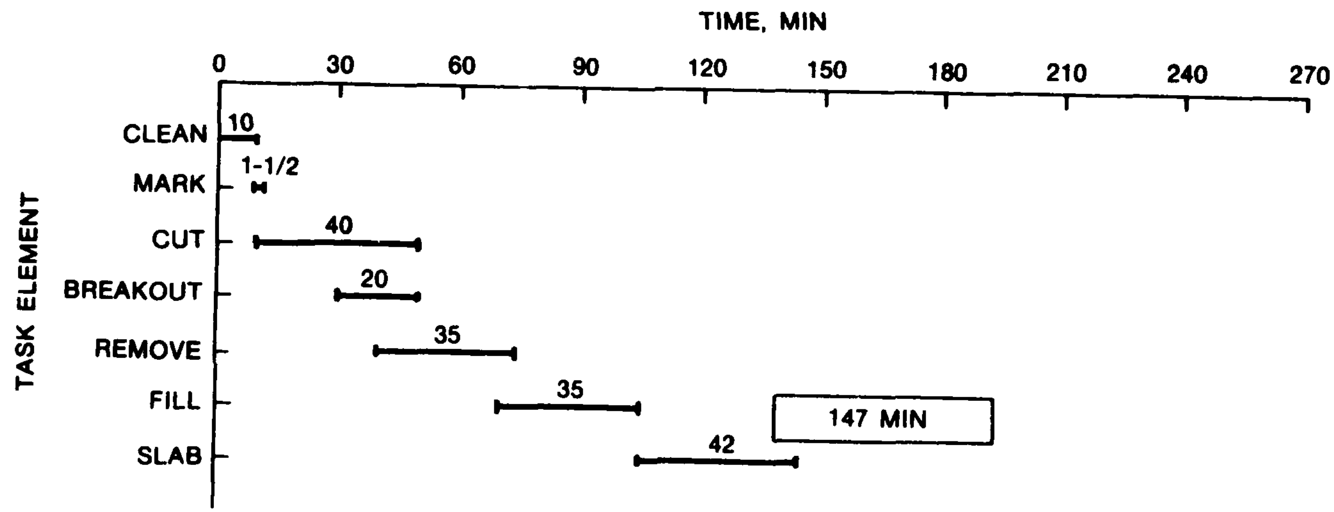

Figure 10. Time Analysis, German Repair Method (6-Meter by 6-Meter Repair).

TABLE 7. TIME AND EQUIPMENT REQUIREMENTS, GERMAN REPAIR METHOD (6-METER BY 6-METER REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader
Mark	1-1/2	Survey Equipment
Cut Concrete	40	1 Concrete Saw
Breakout Concrete	20	1 Hydraulic Hammer
Remove Concrete	35	1 Excavator/1 Loader
Place and Screed Fill	35	1 Loader/1 Compactor/1 Truck
Place Slabs	42	1 Forklift

numbers and types of equipment would be available. Obviously, such estimations must be evaluated through field testing. The time analysis is shown in Figure 11 and the equipment requirements in Table 8. The total estimated time of repair is 205 minutes.

10. Submerged Slab with Rapid-Set Concrete Cap and Debris Backfill (50-Foot by 50-Foot Repair)

This method employs the submerged slab technique in the large crater, and it involves two extremely time-consuming tasks: slab placement and concrete-curing time. Repair of the large crater is based on use of 36 slabs, each 8 feet by 8 feet. Due to the large repair area, potential slab alignment problems, and increased travel distances, it is assumed that each slab would require 2 minutes to place and that two forklifts would be employed. Since each forklift would transport and place 18 slabs, the time requirement for simultaneous operation of both forklifts would be 36 minutes. Thus, 40 minutes were allowed for this task. Placement rate for the grout was based on two mixers, each producing 15 ft^3/min with about 600 ft^3 of grout being required. This results in a minimum estimated time of 20 minutes. Thus, to allow for slippage, 30 minutes were allotted for this task. Finally, a cure time of 1 hour was estimated to allow the concrete grout to cure sufficiently to sustain aircraft traffic. This time analysis is shown in Figure 12 and the equipment requirements in Table 9. A total repair time of 230 minutes is estimated.

11. Flush Slab and Rapid-Set Concrete, Debris Backfill (50-Foot by 50-Foot Repair)

This method is similar to the submerged slab repair except that there is no grout cap; however, the concrete is placed between slabs to enhance load transfer. The individual slab surfaces also constitute the finished upper surface since they are placed flush with the surrounding pavement. The time analysis is shown in Figure 13 and the equipment analysis in Table 10. This repair method will require additional time beyond that required for the submerged slab repair. Since the individual slabs must be placed sufficiently level and flush with the surrounding pavement to meet category A F-4 roughness criteria, more time will be required for grading of the debris backfill, placement of fine aggregate leveling course, and placement of the slabs. The most time-consuming task is slab placement and leveling, for which 72 minutes were allowed. This was based on two forklifts, each placing 18 slabs and allowing 4 minutes per slab. It must be recognized that achievement of an acceptably level repair surface over such a large area will be labor-intensive. The task requirement time for placement of the grout, however, was reduced to 10 minutes since only 160 ft^3 were involved. Total time estimated for this repair is 280 minutes.

12. Submerged Slab with Rapid-Set Concrete, Select Fill (50-Foot by 50-Foot Repair).

This repair method involves removing the major portion of the debris and using select material as the primary backfill because it is impractical to completely clean a crater of this size of all debris and fill it completely with select material. Time element and equipment projections for this repair method are shown in Figure 14 and Table 11, respectively. Some debris material

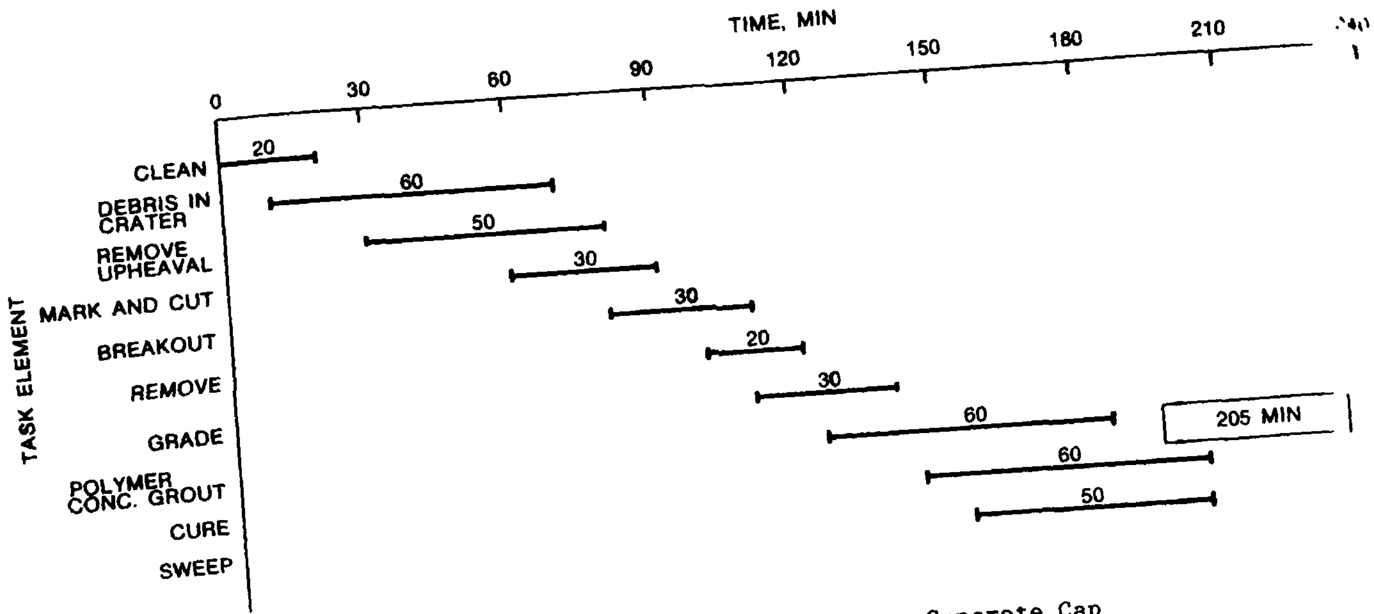

Figure 11. Time Analysis, 8-Inch Polymer Concrete Cap on Debris (50-Foot by 50-Foot Repair).

TABLE 8. TIME AND EQUIPMENT REQUIREMENTS, 8-INCH POLYMER CONCRETE CAP ON DEBRIS (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	60	2 Dozers
Remove Upheaval	50	2 Dozers/2 Front-End Loaders
Mark and Cut Pavement	30	Survey Equipment, Concrete Saws
Breakout	30	Pneumatic Hammer
Remove Broken Pavement	20	2 Dozers/2 Front-End Loaders
Grade Backfill	30	2 Graders
Place Polymer Concrete	60	2 Mobile Mixers
Cure Concrete	60	--
Clean Around Repair	50	Sweeper/Dozer/Grader

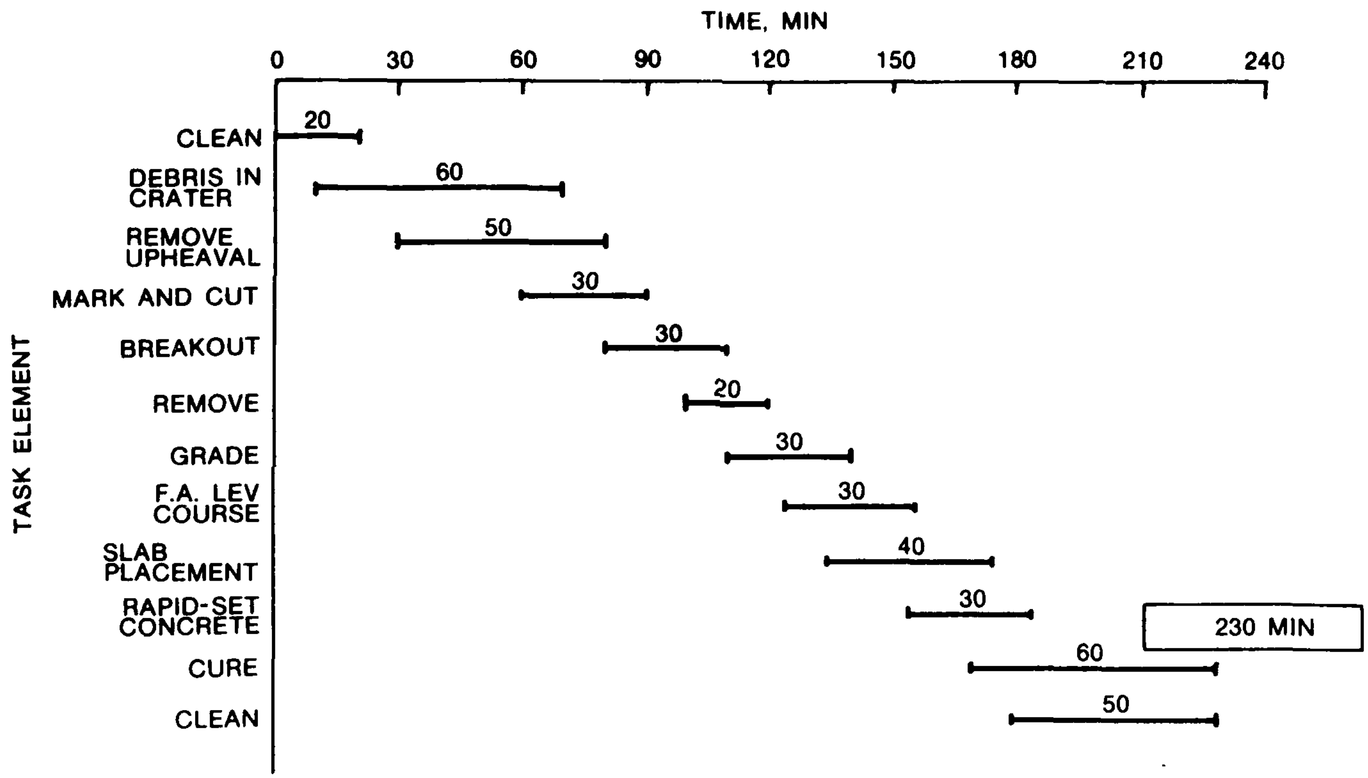

Figure 12. Time Analysis, Submerged Slab with Rapid-Set Concrete Cap, Debris Fill (50-Foot by 50-Foot Repair).

TABLE 9. TIME AND EQUIPMENT REQUIREMENTS, SUBMERGED SLAB WITH RAPID-SET CONCRETE CAP, DEBRIS FILL (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	60	2 Dozers
Remove Upheaval	50	2 Dozers/2 Front-End Loaders
Mark and Cut Pavement	30	Survey Equipment/2 Concrete Saws
Breakout	30	Pneumatic Hammer
Remove Broken Pavement	20	2 Dozers/2 Front-End Loaders
Grade Backfill	30	2 Graders
Fine Aggregate Leveling Course	30	1 Front End Loader/5 Dump Trucks/2 Graders/Screeds
Slab Placement	40	2 Forklifts
Rapid-Set Concrete	30	4 Mobile Mixers/Screeds
Cure Concrete	60	--
Clean Around Repair	20	1 Sweeper/1 Compr. Dozer/Grader

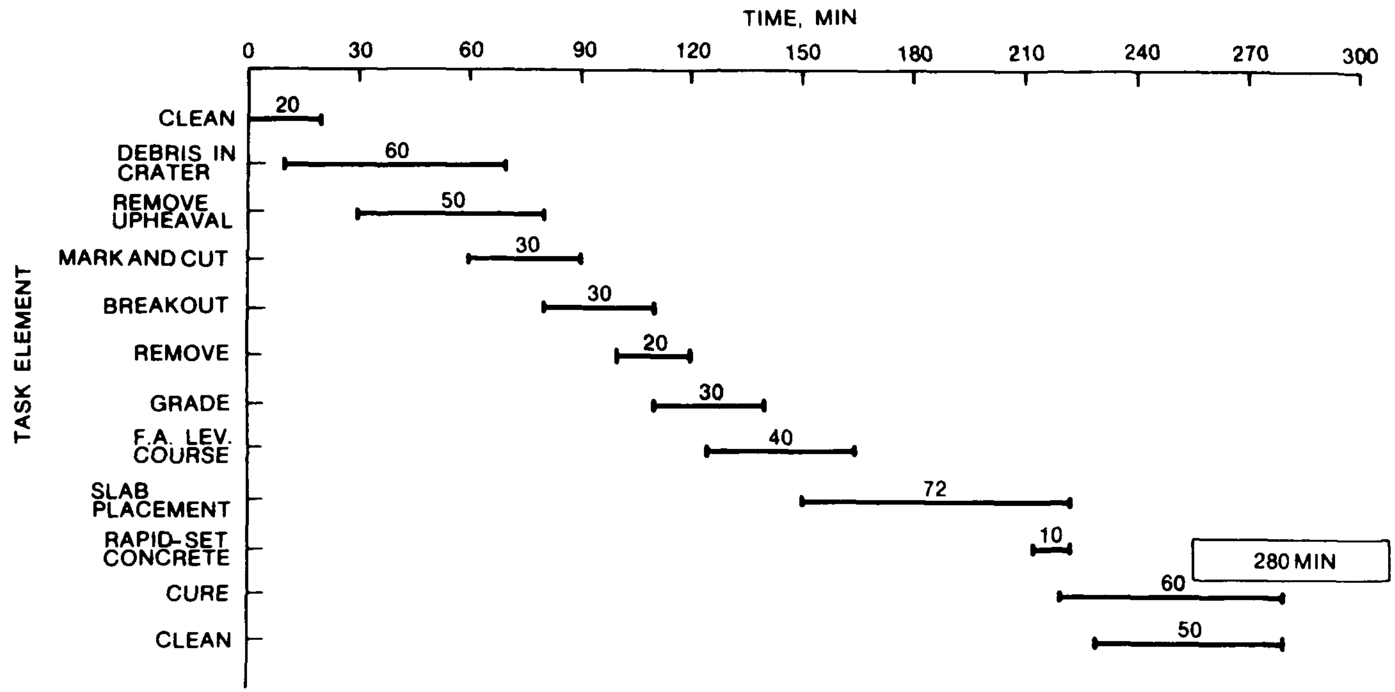

Figure 13. Time Analysis, Flush Slab with Rapid-Set Concrete, Debris Fill (50-Foot by 50-Foot Repair).

TABLE 10. TIME AND EQUIPMENT REQUIREMENTS, FLUSH SLAB WITH RAPID-SET CONCRETE, DEBRIS FILL (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	60	2 Dozers
Remove Upheaval	50	2 Dozers/2 Front-End Loaders
Mark and Cut Pavement	30	Miscellaneous
Breakout	30	1 Pneumatic Hammer
Remove Broken Pavement	20	2 Dozers/Front-End Loader
Grade Backfill	30	2 Graders
Sand Leveling Course	40	1 Front-End Loader/5 Dump Trucks/2 Graders/2 Vibratory Plates/Screeds
Slab Placement	72	2 Forklifts
Rapid-Set Concrete	10	2 Mobile Mixers/Screeds
Cure Concrete	60	--
Clean Around Repair	50	1 Sweeper/1 Compr./1 Dozer/1 Grader

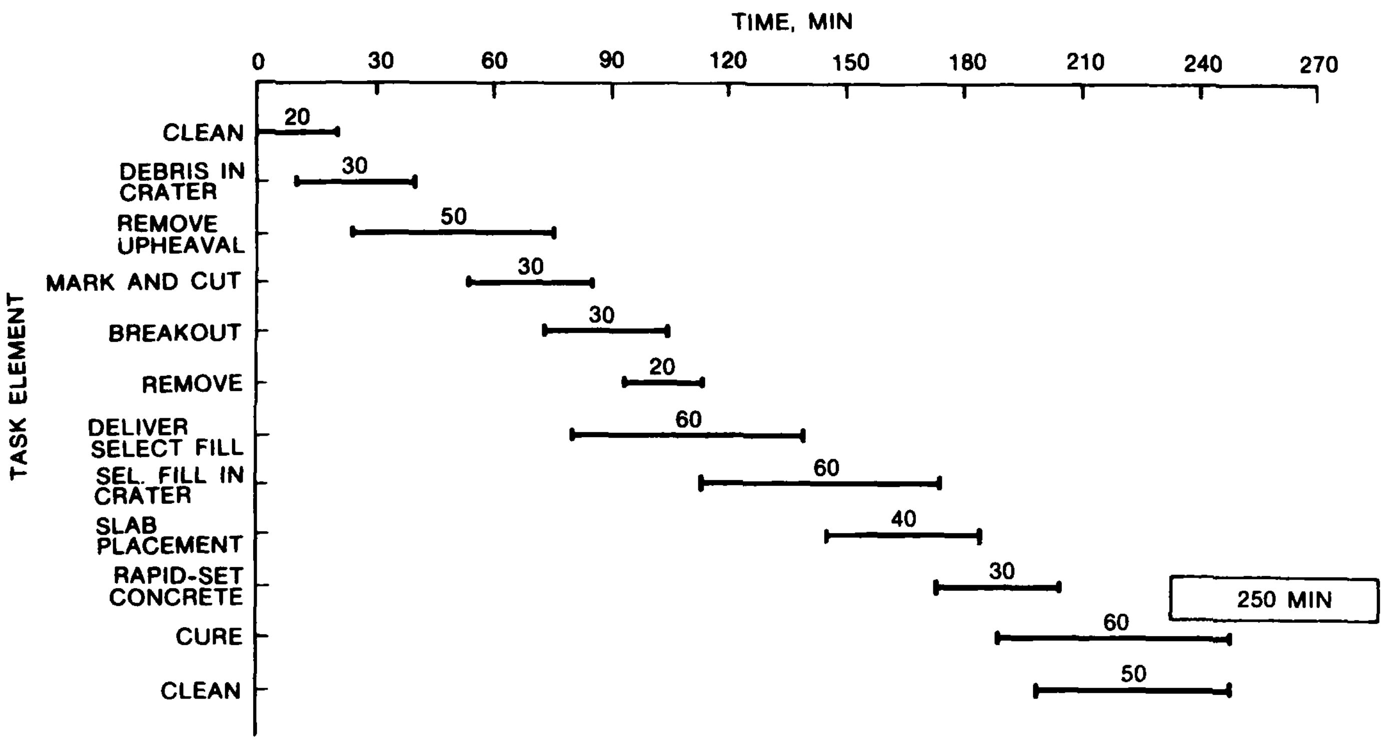

Figure 14. Time Analysis, Submerged Slab with Rapid-Set Concrete, Select Fill (50-Foot by 50-Foot Repair).

TABLE 11. TIME AND EQUIPMENT REQUIREMENTS, SUBMERGED SLAB WITH RAPID-SET CONCRETE, SELECT FILL (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	30	2 Dozers
Remove Upheaval	50	2 Dozers/2 Front-End Loaders
Mark and Cut Pavement	30	Survey Equipment/2 Concrete Saws
Breakout	30	2 Pneumatic Hammers
Remove Broken Pavement	20	2 Dozers/2 Front-End Loaders
Deliver Select Fill	60	10 Dump Trucks/2 Loaders
Select Fill in Crater	60	2 Dozers/2 Graders
Slab Placement	40	2 Forklifts
Rapid-Set Concrete	30	4 Mobile Mixers/Screeds
Cure Concrete	60	--
Clean Around Repair	50	1 Sweeper/1 Compr. Dozer/Grader

would be allowed in the depths of the crater, and the required amount of select material (1-1/2 feet) would be placed over the debris; therefore, the time allotted for placing the debris in the crater would be lowered from 60 to 30 minutes. Similarly, two time elements have been added for delivery of the select material to the crater site (60 minutes) and for placement of the fill in the crater (60 minutes). The resultant trade-off in time elements thus increases the overall estimated time of repair for the material over the debris fill material from 230 minutes to 250 minutes.

13. Flush Slab, Select Fill with Leveling Course (50-Foot by 50-Foot Repair)

Time element and equipment estimates for this repair method are shown in Figure 15 and Table 12, respectively. This repair method involves use of select fill and preparation of a special fine-aggregate leveling course to facilitate placement of the prefabricated slabs. Significant time elements of this repair method include increased time allotted for delivery of the select fill and leveling-course aggregate (70 minutes), reduced time allotted for placement of the select fill (50 minutes), and an additional time element for placement of the leveling course (30 minutes). As with the flush slab-debris fill method, 72 minutes are allotted for placement and leveling of the slabs based on two forklifts, each placing 18 slabs at 4 minutes per slab. Having a total estimated time of repair of 310 minutes, this repair method appears to be the most time-consuming but, in all probability, would be the most advantageous from a structural standpoint.

14. Flush Slab, Select Fill, No Leveling Course (50-Foot by 50-Foot Repair)

Time element and equipment estimates for this repair method are indicated in Figure 16 and Table 13, respectively. This method differs from the preceding repair method primarily in that no special fine aggregate leveling course is provided, and it is assumed that the select fill may be screeded sufficiently level so that the slabs can be placed satisfactorily to meet the desired roughness criteria. However, since aggregate screeding and slab placement in the flush slab methods are time-consuming procedures in general, the overall effect compared with the preceding procedure is a slight reduction in overall repair time to 300 minutes.

15. Submerged Slab on Select Fill, Irregular Repair Opening

An alternate method of preparation of the pavement opening involves the use of pneumatic concrete breakers instead of saw-cutting to trim the broken pavement back for removal of unacceptably rough or tilted pavement pieces. In this method, little attempt would be made to maintain a square opening, and only as many precast slabs as could conveniently be placed in the irregular configuration would be used. The remainder of the opening would be filled with high-quality crushed aggregate. In this analysis several assumptions were made. Since the finished repair would involve areas with no slabs, these areas must be constructed with an adequate thickness of high-quality, well-compacted crushed aggregate to support traffic. Therefore, use of debris backfill would be precluded and only select fill, with high-quality aggregate in the upper layers of the nonslab areas, could be used. Additionally, since the slabs

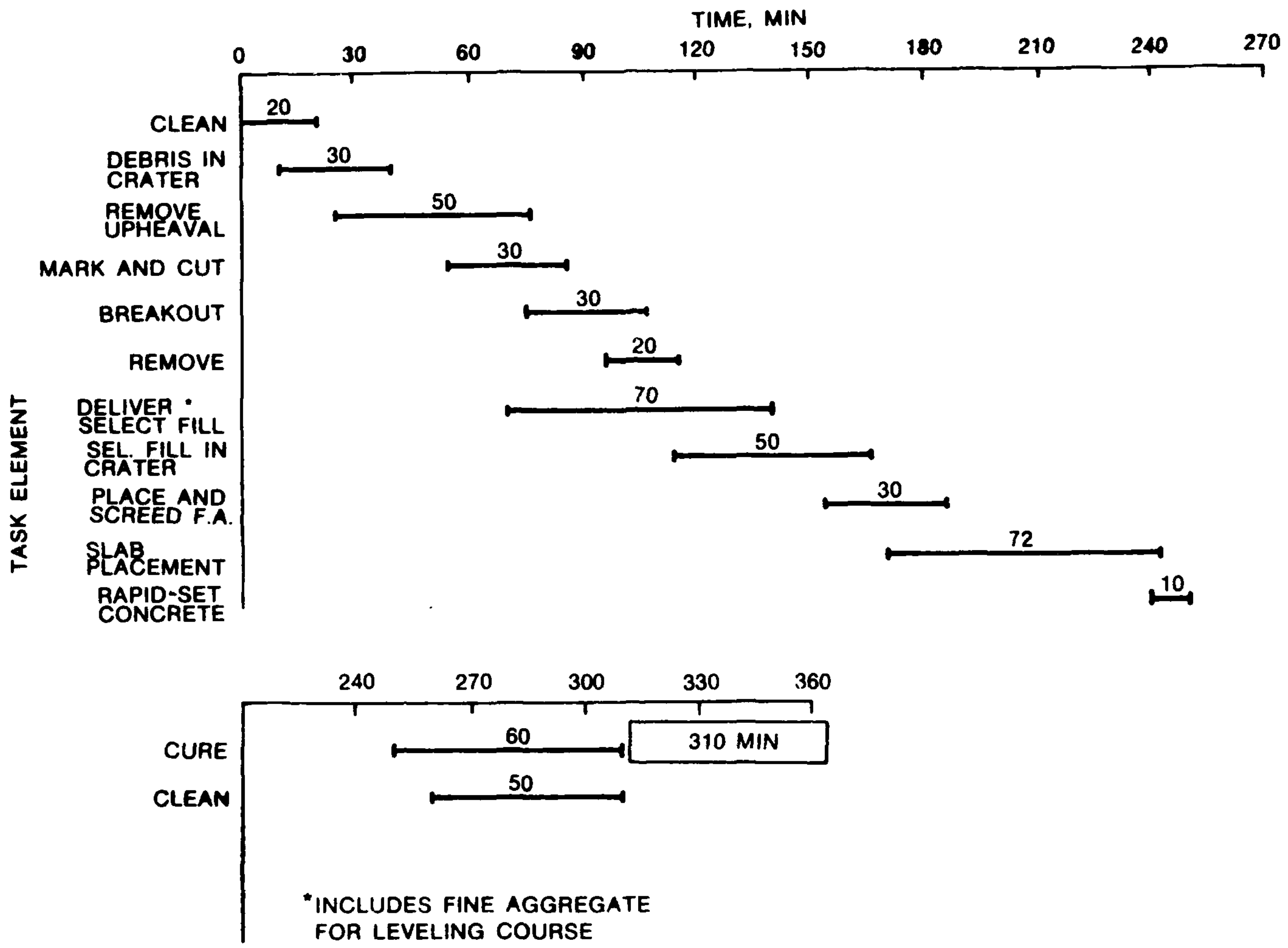

Figure 15. Time Analysis, Flush Slab with Rapid-Set Concrete, Select Fill, Leveling Course (50-Foot by 50-Foot Repair).

TABLE 12. TIME AND EQUIPMENT REQUIREMENTS, FLUSH SLAB WITH RAPID-SET CONCRETE, SELECT FILL, LEVELING COURSE (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	30	2 Dozers
Remove Upheaval	50	2 Dozers/2 Front-End Loaders
Mark and Cut Pavement	30	Survey Equipment/2 Concrete Saws
Breakout	30	2 Pneumatic Hammers
Remove Broken Pavement	20	2 Dozers/2 Front-End Loaders
Deliver Select Fill	70	10 Dump Trucks/2 Loaders
Select Fill in Crater	50	2 Dozers/2 Graders
Place and Screed Fill	30	2 Graders/Screeds
Slab Placement	72	2 Forklifts
Rapid-Set Concrete	10	2 Mobile Mixers/Screeds
Cure Concrete	60	--
Clean Around Repair	50	1 Sweeper/1 Compr./1 Dozer/1 Grader

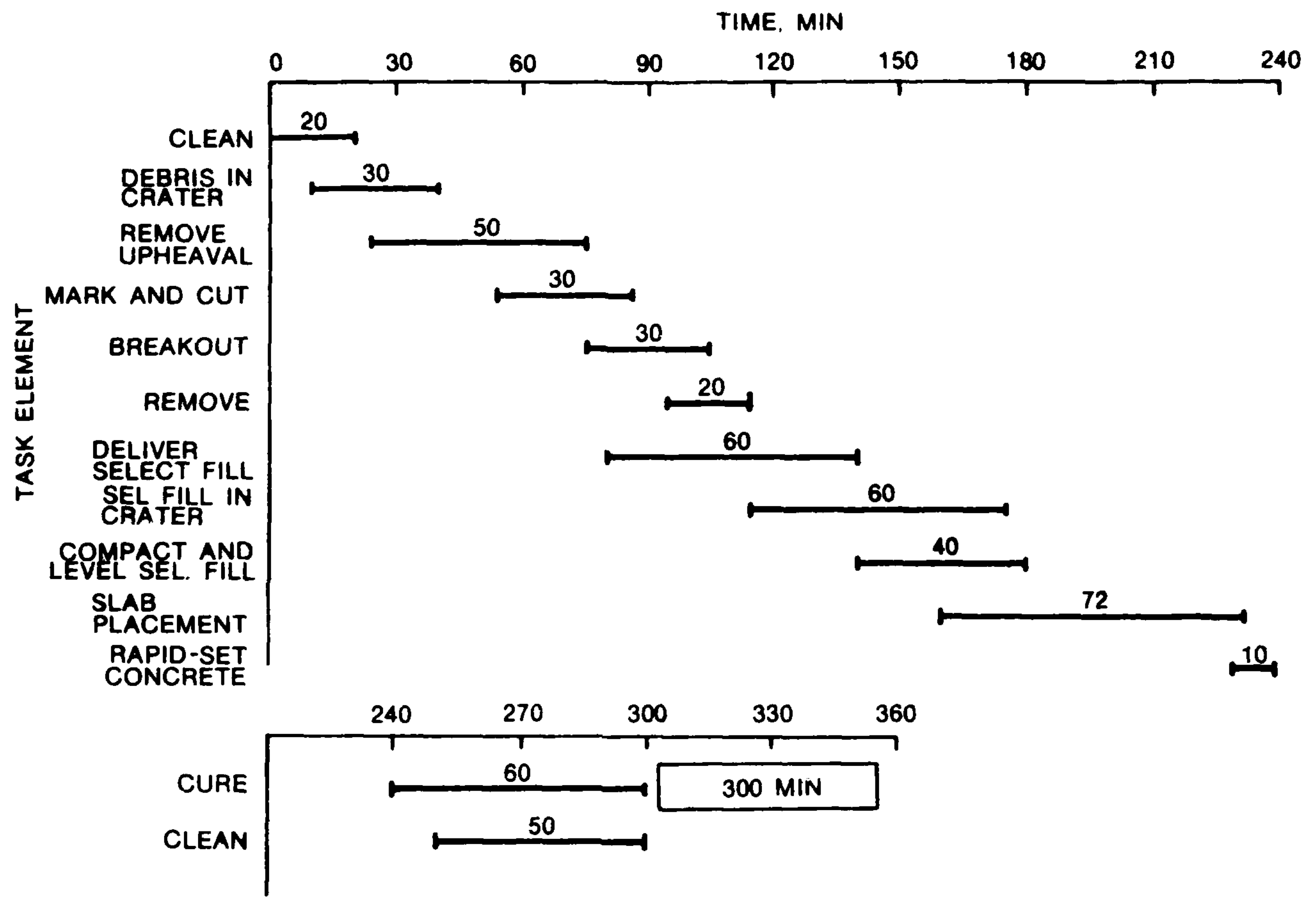

Figure 16. Time Analysis, Flush Slab with Rapid-Set Concrete, Select Fill, No Leveling Course (50-Foot by 50-Foot Repair).

TABLE 13. TIME AND EQUIPMENT REQUIREMENTS, FLUSH SLAB WITH RAPID-SET CONCRETE, SELECT FILL, NO LEVELING COURSE (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	30	2 Dozers
Remove Upheaval	50	2 Dozers/2 Front-End Loaders
Mark and Cut Pavement	30	Survey Equipment/2 Concrete Saws
Breakout	30	2 Pneumatic Hammers
Remove Broken Pavement	20	2 Dozers/2 Front-End Loaders
Deliver Select Fill	60	10 Dump Trucks/2 Loaders
Select Fill in Crater	60	2 Dozers/2 Graders
Compact and Level Select Fill	40	2 Graders/2 Vibratory Rollers
Slab Placement	72	2 Forklifts
Rapid Set Concrete	10	2 Mobile Mixers/Screeds
Cure Concrete	60	—
Clean Around Repair	50	1 Sweeper/1 Compr./1 Dozer/ 1 Grader

that would be used will be nested in the center area of the opening, it would appear that the difficulty in leveling slabs in this configuration would preclude the flush slab approach. Therefore, this analysis is based on the submerged slab concept. For this type of repair, it is also assumed that, for smoothness, a rapid-set concrete cap will be placed over the entire surface, including slabs and compacted crushed aggregate. In order to develop a basis for the size of the repair, although the opening in the pavement formed with pneumatic breakers would have a jagged perimeter, calculations were based on a circular opening with a diameter of 50 feet and an area of approximately 1964 square feet. Based on these assumptions, a time analysis was made for this type of repair. The time analysis and equipment estimate are shown in Figure 17 and Table 14, respectively. The estimated total time of repair is 250 minutes. In comparing this method of repair with the submerged slab on select fill repair in a 50-foot by 50-foot square cut opening, it may be seen that trade-offs in time estimates for the various task elements resulted in a total time of repair for the irregular opening method being the same as for the square opening repair, i.e., 250 minutes. For example, the combined time allotment for the square opening for marking and cutting the pavement and breakout of upheaved pieces was 50 minutes. These elements have been combined for the irregular opening repair into one element with a time allotment of 30 minutes. In the latter method of repair, it was assumed that the pavement would simply be marked back to acceptably level areas and all pavement pieces removed. Less time would be required in marking and breaking the pavement. Additional time was also allowed for delivery of the fill (70 minutes) since more material would be required. Also, since more compaction would be necessary, particularly in the nonslab areas, the time element for placement of the fill was extended to 90 minutes. The time allotment for slab placement was reduced to 25 minutes; however, this task could be accomplished simultaneously with the final stage of placement of the select fill. Therefore, some time expenditures could be shortened at this point. Placement time for the rapid set concrete was only slightly reduced to 25 minutes.

C. STRUCTURAL ANALYSIS

1. Approach and Assumptions

Analysis of the structural characteristics of the various repair techniques consisted of calculation of tensile stress in the individual slab or grouted slabs and of the vertical stress at the surface of the foundation material or subgrade. In addition to stress analysis of the test structures which involved plain concrete slabs, analyses were made based on hypothetical use of composite and steel fiber-reinforced slabs. A composite slab is one having a plain concrete upper layer and a polymer concrete lower layer. Three computer programs were used for the stress calculations: BISAR (Reference 6), WESLAYER and WESLIQID (Reference 7). BISAR is based on layered elastic theory; WESLAYER and WESLIQID represent a finite element slab on an elastic-layered foundation and on a Winkler (dense liquid) foundation, respectively. The procedure for developing a slab thickness design with the BISAR program was to establish a two-layer model to calculate the slab and subgrade stresses. The upper layer constituted the total pavement structure, including slabs, grout, and cap when appropriate. The fill material or subgrade constituted the lower layer. This program was used to simulate a repair involving load transfer between slabs. The WESLAYER and WESLIQID programs were used for

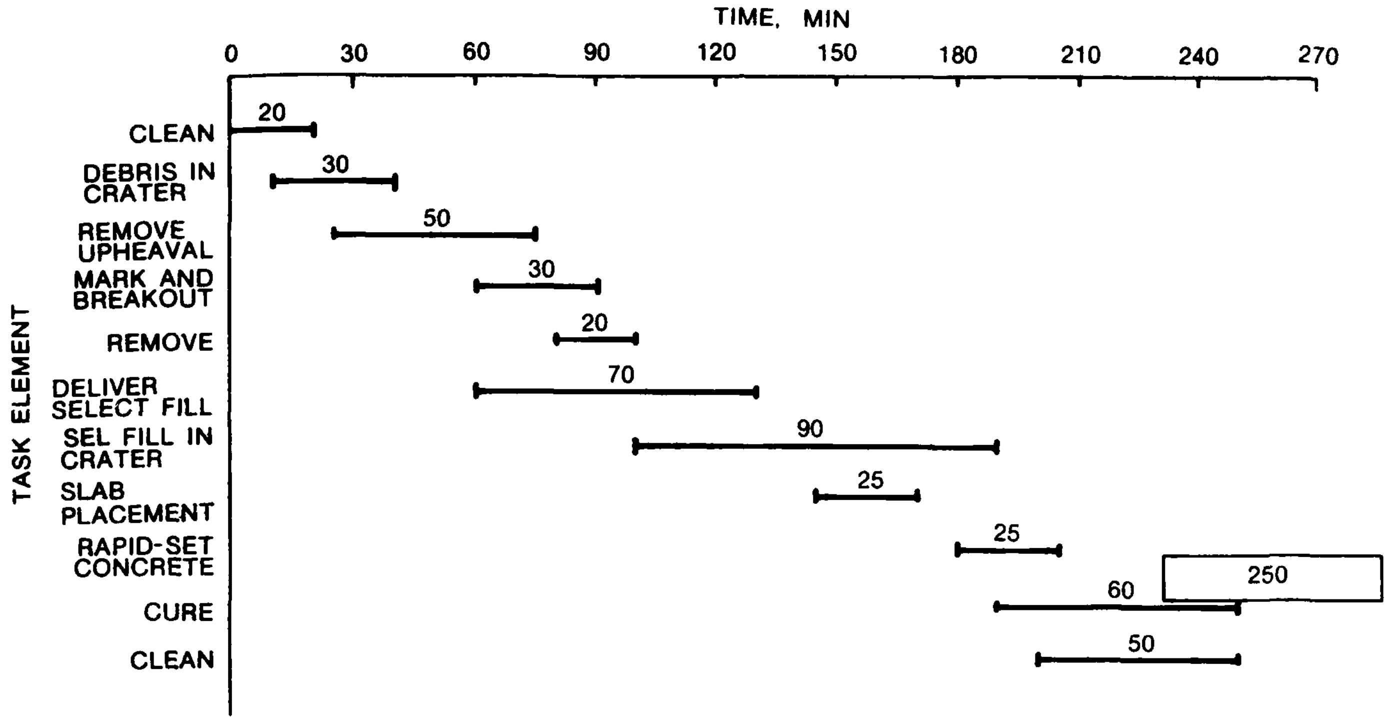

Figure 17. Time Analysis, Submerged Slab with Rapid-Set Concrete, Select Fill, Irregular Opening (50-Foot by 50-Foot Repair).

TABLE 14. TIME AND EQUIPMENT REQUIREMENTS, SUBMERGED SLAB WITH RAPID-SET CONCRETE, SELECT FILL, IRREGULAR OPENING (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	30	2 Dozers
Remove Upheaval	50	2 Dozers/1 Front-End Loader
Mark and Breakout	30	Survey Equipment/2 Pneumatic Pavement Breakers
Remove Broken Pavement	20	2 Dozers/2 Front-End Loaders
Deliver Select Fill	70	10 Dump Trucks/2 Loaders
Select Fill in Crater	90	2 Dozers/2 Graders/2 Vibratory Compactors
Slab Placement	25	2 Forklifts
Rapid-Set Concrete	25	4 Mobile Mixers/Screeds
Cure Concrete	60	--
Clean Around Repair	50	1 Sweeper/1 Compr. Dozer/Grader

analysis of individual slabs with no load transfer. The WESLAYER program was used when the fill material was layered and the WESLIQID program was used for homogeneous fill. Input parameters for BISAR and WESLAYER are structural characteristics of the layer in terms of modulus of elasticity, F, Poisson's ratio, ν, and loading geometry. Input for WESLIQID are values of E and ν for the slab, modulus of soil reaction, k, for the foundation, and loading geometry. For this study the critical load was determined to be a C-141, and the loading configuration used for the stress computations consisted of one main landing gear of that aircraft. Therefore, the loading geometry consisted of four wheels, each having a load of 36,000 pounds and contact pressure of 173 psi. Values of E used for the plain concrete and polymer concrete were 4×10^6 psi and for the steel fiber-reinforced concrete 5.5×10^6 psi. Limiting values of tensile stress were based on values assumed for the modulus of rupture for the various materials. For the plain concrete, polymer concrete, and fibrous concrete, modulus of rupture values were 700, 1600, and 1000 psi, respectively. Poisson's ratios for the concrete and fill materials were assumed as 0.15 and 0.40, respectively.

2. Submerged Slab with Rapid-Set Concrete Cap

The model for this analysis was a two-layered elastic system using the structural properties of portland cement concrete for the upper layer and a backfill with a strength of 4 CBR for the lower layer. Calculations were made using the BISAR program for slab thicknesses of 4, 6, 8, and 10 inches. The design configuration for this repair calls for a 2-inch thick cap of rapid-set concrete. For this analysis, the modulus of elasticity of rapid-set concrete and portland cement concrete were assumed to be about equal, i.e., 4×10^6 psi. Since the slabs are essentially incorporated into a concrete matrix, the modeling concept of a monolithic slab for the upper layer appears valid. The upper 2 inches of repair will be in compression, and there will be little structural benefit with respect to slab bending. Values of maximum tensile stress at the lower surface of the upper layer and the corresponding vertical stress in the debris backfill for each structure are shown in Table 15.

TABLE 15. STRESS ANALYSIS, PCC SLABS ON DEBRIS BACKFILL.

Slab Thickness in.	Maximum Tensile Stress at Bottom of Slab psi	Vertical Stress Debris Backfill psi
4	1770	22.5
6	1130	14.2
8	855	10.0
10	672	7.4

Plots of these values are shown in Figure 18. If a modulus of rupture value for the concrete of 700 psi is assumed, a total thickness requirement of 9.4 inches is indicated. Assuming that the rapid-set concrete constitutes the upper 2 inches of repair, then the thickness of the precast slab would

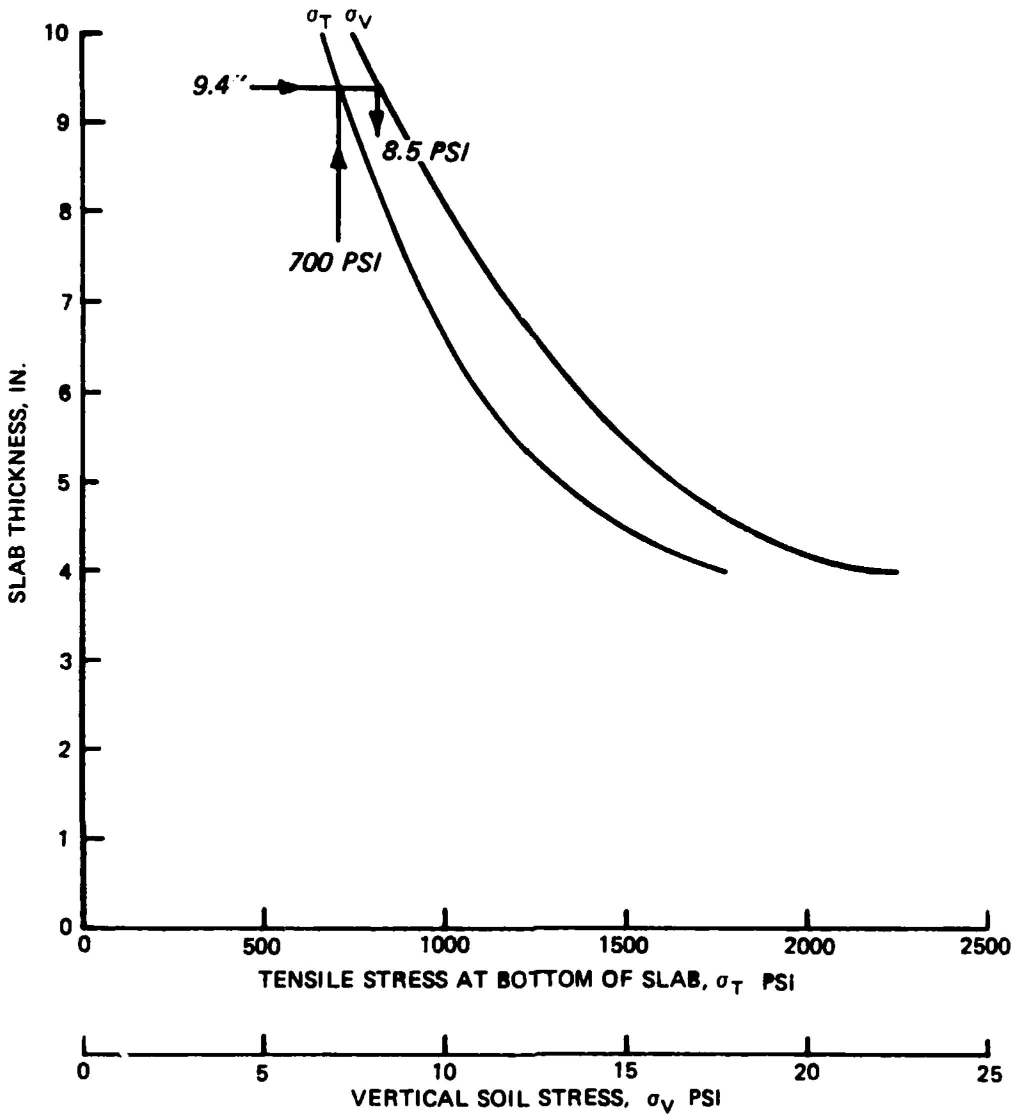

Figure 18. Stress Analysis, Submerged and Flush PCC Slabs in Polymer Concrete Matrix.

be 7.4 inches. It should be remembered that these values are based on static loading taken at the rupture or critical value for plain portland cement concrete. The indicated value of vertical subgrade stress is 8.5 psi. For conventional pavement structures, it is generally desired that the vertical subgrade stress not exceed 10 psi; however, higher values may be acceptable for expedient repair with limited traffic.

3. Flush Slab with Polymer Concrete Grout

The model used for structural analysis of this repair was the same as that used for the submerged slab repair since, in this configuration, the slabs are simply grouted together for continuity. Therefore, again using Figure 18, a total thickness value of the upper layer of 9.4 inches is

indicated at the critical stress state under static loading. This value may thus be taken as the theoretical required thickness of the precast slabs used in this type of repair. Again, it should be noted that these units are unreinforced concrete.

4. Submerged Composite Slabs with Rapid-Set Concrete Cap

For this analysis, a composite slab is defined as one made up of two bonded layers with the upper layer consisting of portland cement concrete and the lower layer consisting of polymer concrete. Again, the two-layer model was used assuming the slabs to be submerged in a concrete matrix; however, the maximum allowable tensile stress at the layer bottom was assumed to be 1600 psi. Conceptually, the interface boundary between layers defining the minimum thickness of the polymer concrete could be taken as that point at which the value of the tensile stress is reduced to 700 psi, or the maximum allowable flexural stress for plain portland cement concrete.

Obviously this concept may not be entirely accurate since that would be a point of interior and not extreme fiber stress, and the effectiveness of the bonding between layers would influence the stress concentrations at the interface. Figure 19 shows plots of maximum tensile stress at the bottom of the slab and maximum vertical stress at the top of the subgrade, both compared with slab thickness. For a tensile stress value of 1600 psi, a slab thickness of 4.2 inches is indicated. The corresponding subgrade stress is 20.0 psi. Based on a debris backfill strength of 4 CBR, it could reasonably be concluded that a vertical stress of this magnitude could induce shear failure in the underlying soil. If the allowable vertical soil stress is reduced to about 12.5 psi, the tensile stress in the slab is indicated to be about 1000 psi for a slab thickness of 6.6 inches. It has been shown in laboratory tests that, for soils of low strength and density, a repeated vertical stress of about 12.5 psi at low confining pressures is the maximum average stress level that is tolerable (Reference 8). At these values of stress and thickness, low but acceptable traffic levels can be tolerated, and some advantage can be taken of the flexural strength of the polymer cement.

To estimate the required thickness of the polymer layer in the composite slab, an examination of the stress distribution through the upper layer for a thickness of 6.6 is required. This stress distribution is shown in Figure 20. From this stress analysis, the value of tensile stress of 700 psi, the maximum allowable flexural stress for the upper layer of portland cement concrete, occurs at a depth of 5.5 inches. Therefore, the minimum thickness indicated for the polymer layer is 1.1 inches. Since it is assumed that the upper 2 inches of repair are polymer concrete cap, the total theoretical thickness of precast slab is 4.6 inches with 3.5 inches of portland cement concrete for the upper layer and 1.1 inches of polymer concrete for the lower layer.

5. Flush Composite Slabs with Rapid-Set Concrete Grout

This concept envisions the use of composite slabs grouted together at the edges with rapid set concrete to provide load transfer. Based on the two-layered elastic model, the stress patterns shown in Figure 19 are again applicable. Based on the assumptions and discussion presented previously for the submerged composite slab repair, a total repair thickness of 6.6 inches would appear appropriate. Since this repair involves no concrete cap, the precast

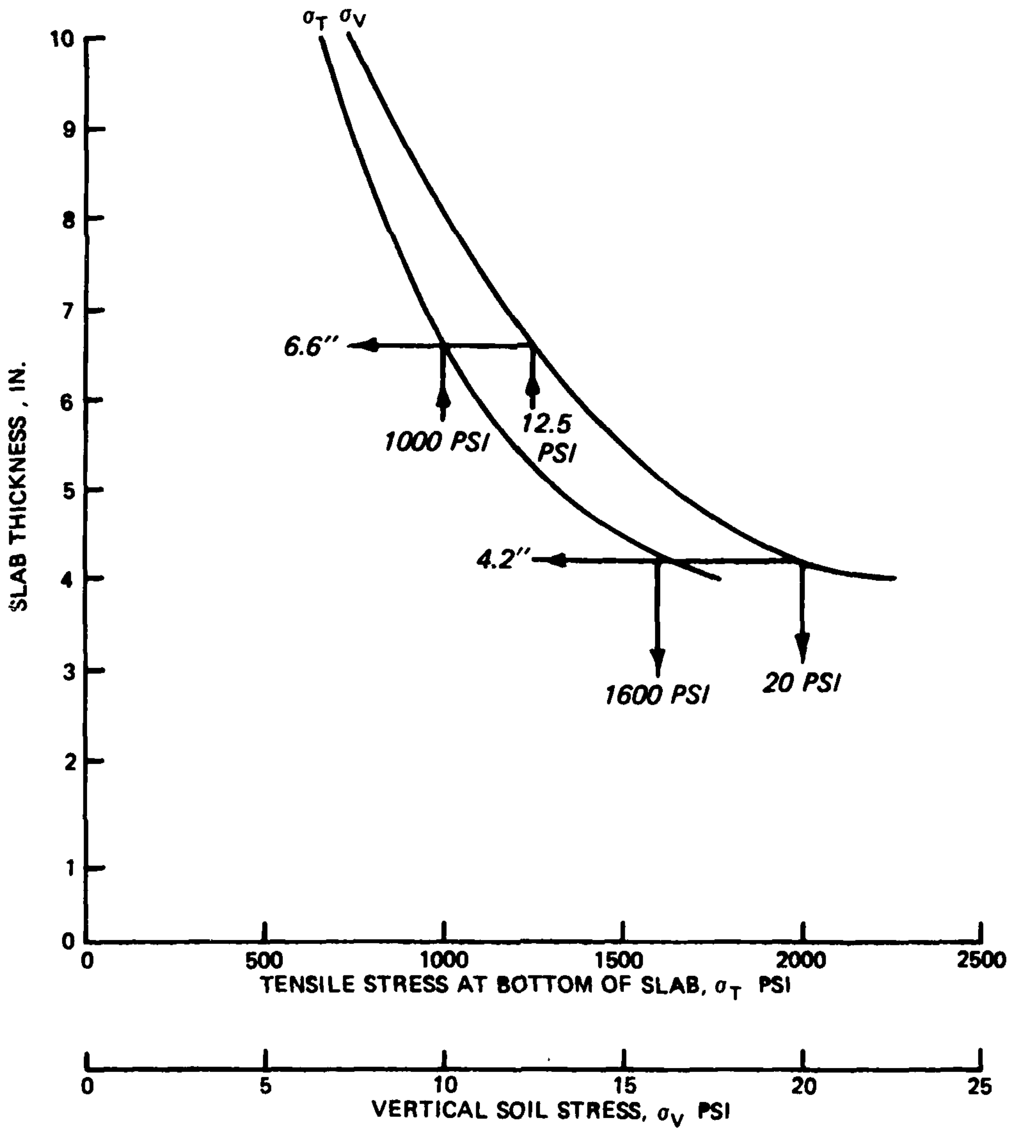

Figure 19. Stress Analysis, Submerged and Flush Composite Slab in Polymer Concrete Matrix.

slab thickness also would be 6.6 inches. Again, the stress distribution pattern indicated in Figure 20 applies; thus, the theoretical design for each slab would involve an upper layer consisting of 5.5 inches of portland cement concrete and 1.1 inches of polymer concrete.

6. Submerged Fibrous Concrete Slab with Rapid-Set Concrete Cap

This repair concept involves the use of precast concrete slabs reinforced with steel fibers. The two-layered elastic model was also used in the analysis; however, the structural properties of the stiffer fibrous concrete were used to characterize the upper layer. Stress calculations were

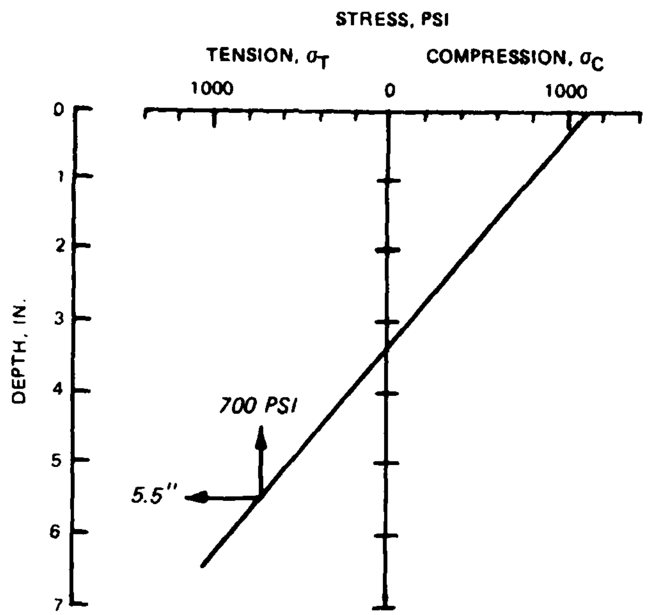

Figure 20. Stress Distribution, Composite Slab in Polymer Concrete Matrix.

made for thicknesses of 4, 6, and 8 inches. Computed values of the maximum tensile stress at the bottom of the upper layer and maximum vertical stress at the top of the debris backfill are shown in Table 16. A plot of these values is shown in Figure 21. From Figure 21, it can be seen that for a limiting stress value in the fibrous concrete of 1000 psi, a thickness of 7.3 inches is indicated. The corresponding value for the soil stress in the debris backfill is 9.8 psi, which is within acceptable limits. Assuming that there will be a 2-inch-thick rapid-set concrete cap on the fibrous concrete slab, the actual slab thickness is reduced to 5.3 inches. These computations are based on theoretical limiting stress for static loading and do not incorporate the traffic fatigue effect into the calculation process.

TABLE 16. STRESS ANALYSIS, FIBROUS CONCRETE SLABS ON DEBRIS BACKFILL.

Slabs Thickness in.	Maximum Tensile Stress at Bottom of Slab psi	Vertical Stress Debris Backfill psi
4	1940	19.9
6	1270	12.5
8	948	8.64

7. Flush Fibrous Concrete Slabs with Rapid Set Concrete Grout

Based on the two-layered elastic model with fibrous concrete properties for the upper layer, an analysis was made for the flush slab concept. Again, Figure 21 applies; however, the total thickness indicated, 7.3 inches, would be the theoretical thickness for the slabs alone.

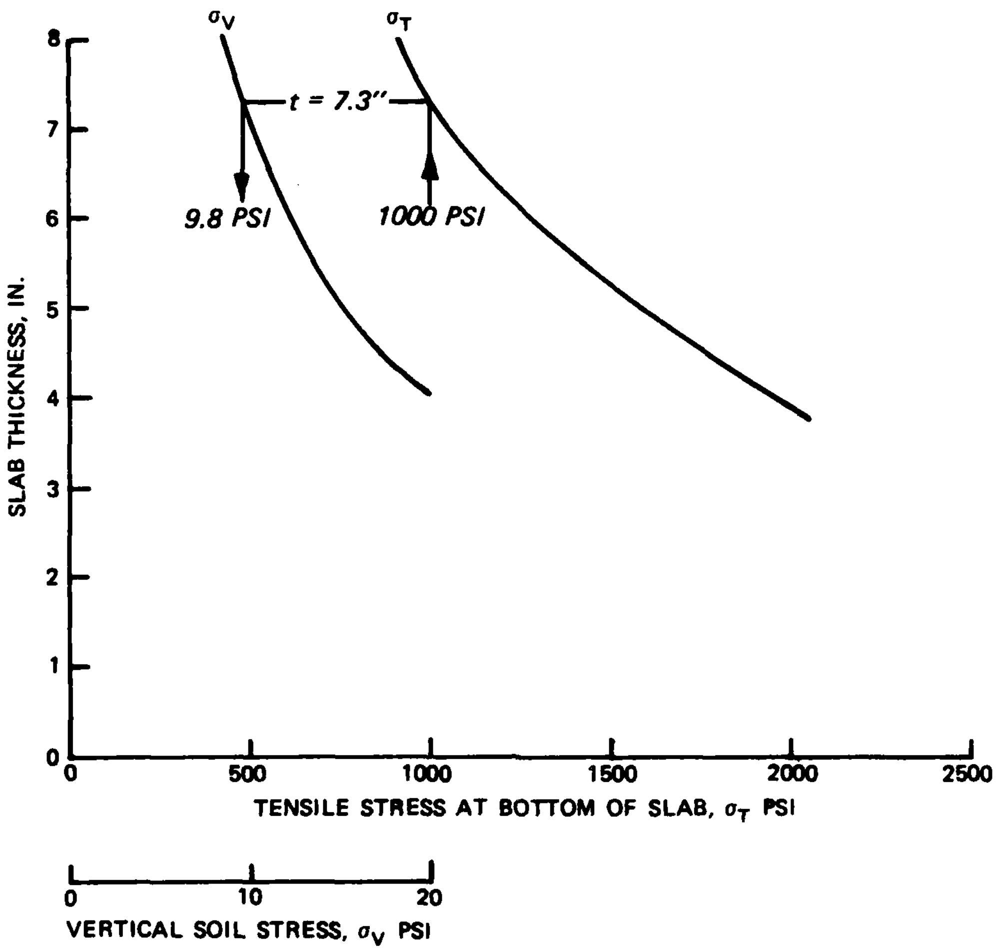

Figure 21. Stress Analysis, Submerged and Flush Fibrous Concrete Slab in Polymer Concrete Matrix.

8. German Repair Method

This repair concept involves the use of reinforced concrete slabs, approximately 6 feet by 6 feet square and 6 inches thick, placed on 10 inches of fine aggregate and 9 inches of coarse aggregate all over a debris backfill. There is no load transfer between slabs. For this analysis the WESLAYER computer program was used. The model involves the loaded slab on a layered elastic foundation. Results of the analysis indicate that the maximum tensile stress at the bottom of the slab was approximately 588 psi, and the maximum vertical

stress at the top of the granular layer was approximately 78 psi. The tensile stress in the slab is well below the flexural strength of the concrete. The high value of vertical stress in the granular fill reflects the stiffness of the fill and lack of development of bending in the slab. For well-compacted granular fill with some confinement, this value, although large, does not appear to be excessive.

9. German Slab on Debris Backfill

This analysis involves placement of 6-foot by 6-foot slabs directly on debris backfill with no load transfer between slabs. The strength of the backfill was assumed to be about 4 CBR, or 100 pci. The WESLIQID program was used for this analysis. Four slab thicknesses were analyzed: 4, 6, and 8 inches. Values calculated were maximum tensile stress in the slab and maximum vertical stress at the top of the debris. Results of the analysis are shown in Table 17. These values are plotted in Figure 22. Based on a concrete flexural strength of 700 psi, a slab thickness of 7.7 inches is indicated. The subgrade stress value associated with this slab configuration is 44.8 psi. This value is lower than that for a granular fill due to the softer foundation; however, it could be excessively large and lead to shear failure in the weaker type soil.

10. Composite Slab on Debris Backfill

For the analysis, the WESLIQID program was also used, and the slab size was assumed as 6 feet by 6 feet. In this concept, it is assumed that the slabs rest on debris backfill with no load transfer mechanism. Assuming that the polymer concrete lower layer of the composite slab has a maximum flexural strength of 1600 psi, a minimum slab thickness of 5.1 inches is indicated (see Figure 23). The associated vertical soil stress is 50 psi. In order to determine the minimum thickness of polymer concrete required for the composite slab, location of the depth in the slab at which the tensile strength is reduced to 700 psi was determined (Figure 24). This stress value is found at 3.7 inches below the slab surface. Therefore, a composite slab for this repair concept would consist of 3.7 inches of portland cement concrete and 1.4 inches of polymer concrete.

TABLE 17. STRESS ANALYSIS, 6-FOOT BY 6-FOOT PCC SLAB ON DEBRIS BACKFILL, NO LOAD TRANSFER.

Slab Thickness in.	Maximum Tensile Stress in Slab psi	Vertical Stress in Debris psi
4	2329	53
6	1166	47
8	678	45

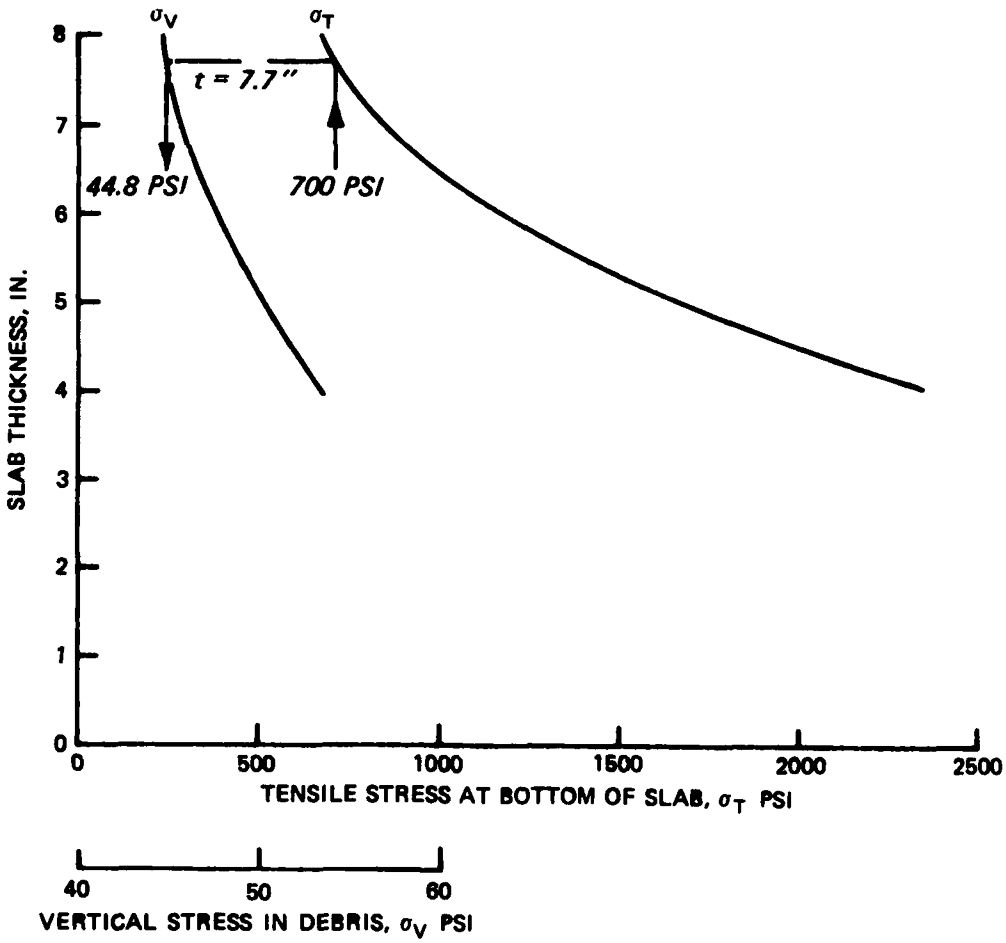

Figure 22. Stress Analysis, 6-Foot by 6-Foot PCC Slab on Debris Backfill, No Load Transfer.

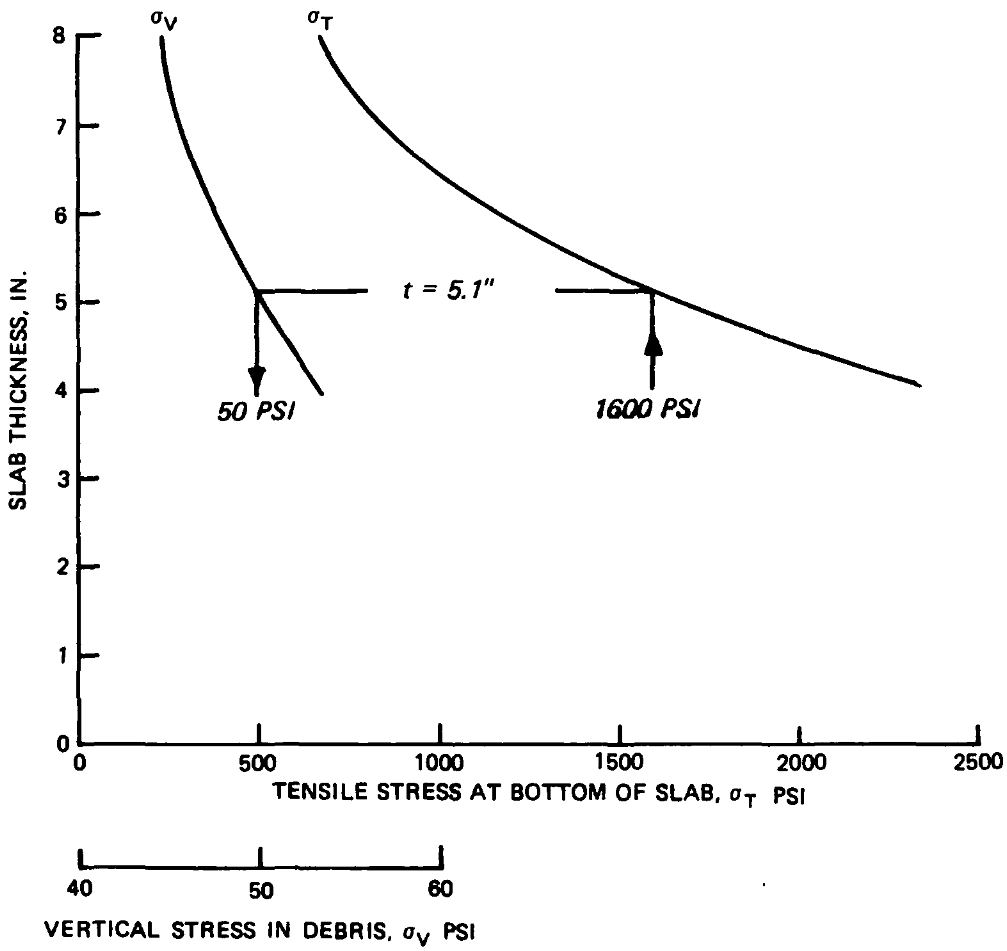

Figure 23. Stress Analysis, 6-Foot by 6-Foot Composite Slab on Debris Backfill, No Load Transfer.

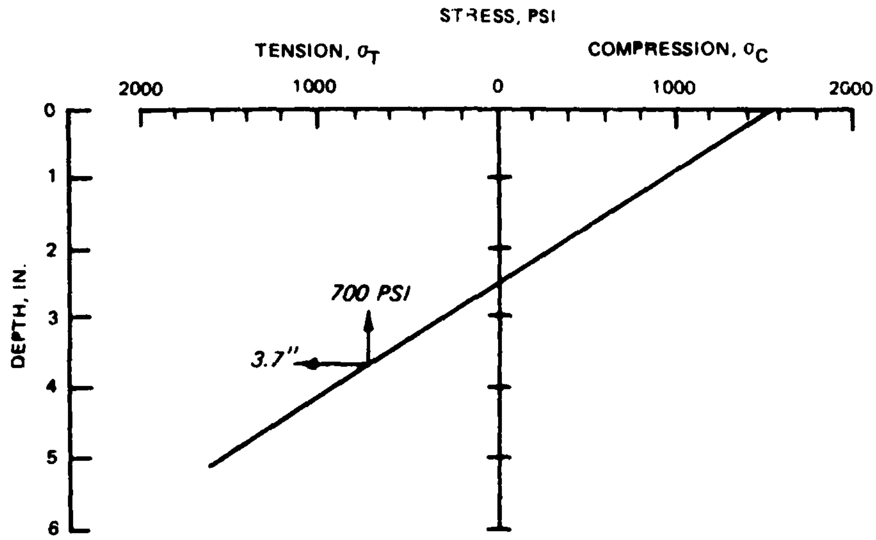

Figure 24. Stress Distribution, 6-Foot by 6-Foot Composite Slab on Debris Backfill, No Load Transfer.

11. Fibrous Concrete Slab on Debris Backfill

This repair concept involves use of a 6-foot by 6-foot steel fiber reinforced concrete slab on debris backfill. Again, no load transfer is involved. The WESLIQID program was used for analysis of three slab thicknesses: 4, 6, and 8 inches. Results of the analysis are shown in Table 18. These data are plotted in Figure 25. Based on a maximum flexural strength for the fibrous concrete of 1000 psi, a slab thickness of 6.5 inches is indicated. Again, however, the vertical stress in the debris backfill, 45.3 psi, appears to be excessively large.

D. EVALUATION

1. Time Analysis

A summary of the total time of repair (minutes) and rate of repair (square feet/minute) for each method as determined from time analyses is shown in Table 19.

For small crater repair, the German method is indicated as being the most rapid, with a repair rate of 4.69 square feet/minute (ft^2/min). As indicated, these data were obtained from reported on-site observations. The next most competitive method on a time rate of repair basis is the polymer concrete cap on debris method at 3.33 ft^2/min. This method, however, does not involve the use of precast slabs, which was the basis for this study, and this time estimate was developed primarily to provide baseline data against which the various precast slab repair methods could be compared. Total time of repair for the polymer cap is 120 minutes. The most competitive of the precast slab repair methods,on a time basis,appear to be those involving submerged slab techniques. The rate of repair for the submerged slab methods

TABLE 18. STRESS ANALYSIS, FIBROUS CONCRETE SLAB ON DEBRIS BACKFILL.

Slab Thickness in.	Maximum Tensile Stress in Slab psi	Vertical Stress in Debris psi
4	2430	51
6	1184	46
8	683	44

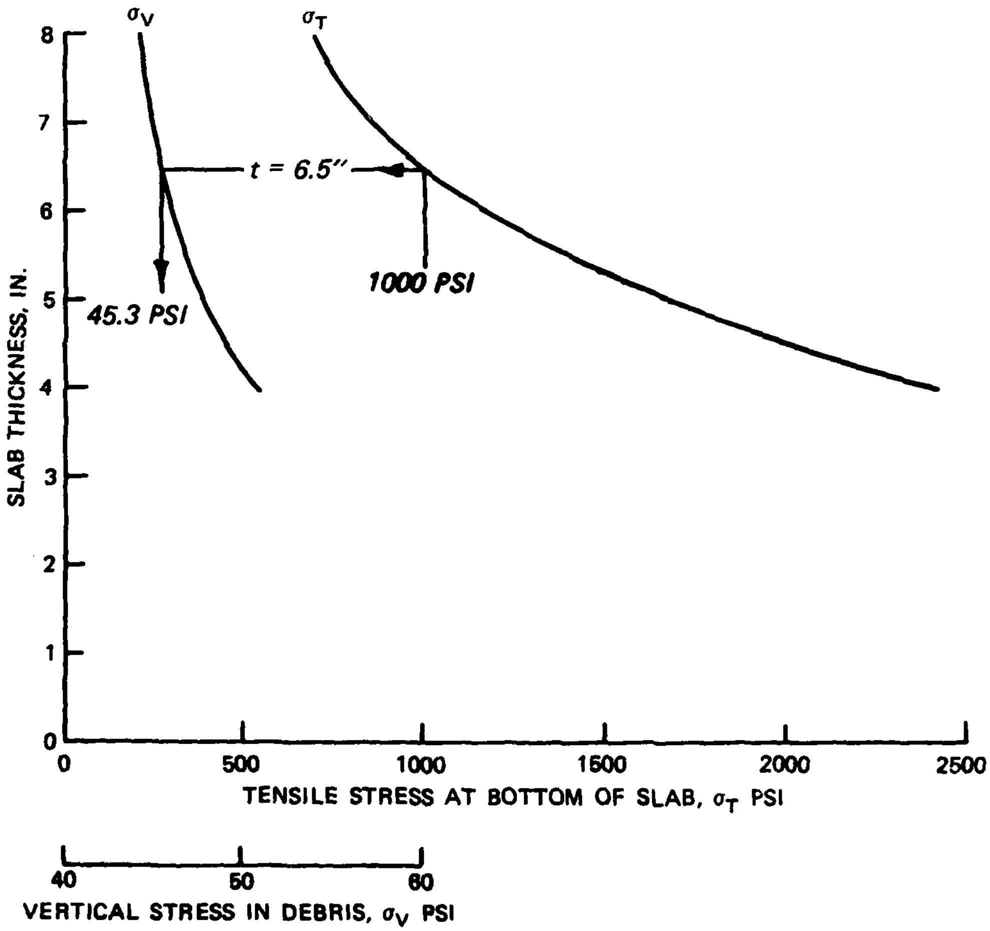

Figure 25. Stress Analysis, 6-Foot by 6-Foot Fibrous Concrete Slab, Debris Backfill, No Load Transfer.

TABLE 19. SUMMARY OF REPAIR TIME DATA.

Repair Method	Repair Time (minutes)	Rate (square feet/minute)
20-foot by 20-foot crater		
Polymer cap on debris	120	3.33
Submerged slab - debris	180	2.22
Flush slab - debris	195	2.05
Submerged slab - select fill	185	2.16
Flush slab - select fill - leveling course	210	1.90
Flush slab - select fill - no leveling course	200	2.00
German method, 8 meters by 8 meters	147	4.69
50-foot by 50-foot crater		
Polymer cap on debris	205	12.20
Submerged slab - debris	230	10.87
Flush slab - debris	280	8.93
Submerged slab - select fill	250	10.00
Flush slab - select fill - leveling course	310	8.07
Flush slab - select fill - no leveling course	300	8.33
Submerged slab - irregular opening	250	7.85

on debris and on select fill are 2.22 and 2.16 ft^2/min, respectively. The total times of repair for these methods are 180 and 185 minutes, respectively. The time trade-off between the two methods involves using debris backfill with a leveling course as opposed to using select material backfill with no leveling course, the result being little difference in overall time of repair. The flush slab repair methods are the most time-consuming, primarily because additional time allotments have been made for placement and leveling of the individual slabs. Time allotments for slab placement in the submerged and flush slab methods are 15 and 30 minutes, respectively. In the select fill method with a leveling course, which would facilitate achieving the desired roughness criteria, the total time of repair is 210 minutes at a rate of 1.90 ft^2/min. The rates of repair for the flush slab on debris and flush slab on select fill without a leveling course are 2.05 and 2.00 ft^2/min, respectively.

In developing time analyses for the 50-foot by 50-foot repair, an 8-inch polymer concrete cap placed on debris backfill also was used as a standard for comparison. The total estimated time of repair and repair rate were 205 minutes and 12.20 ft^2/min, respectively. Time estimates for this and all 50-foot by 50-foot repair methods were based on the assumption that the optimum equipment and manpower would be available.

As with the 20-foot by 20-foot repair, the submerged slab repair methods in the square opening appear to offer the most rapid approach. Repair rates for the submerged slab on debris and submerged slab on select fill are 10.87 and 10.00 ft^2/min, respectively. Total respective repair times for these methods are 230 and 250 minutes. In comparing repair methods involving debris fill versus select fill, the time trade-off is made by allowing 60 minutes for debris fill-time in the former method versus allowing only 30 minutes for that element in the latter method but providing a 60-minute select fill-time element. Time element overlaps obviously compress the time differences so that the net effect results in little difference in total repair times. The flush slab repair methods will require considerably more time primarily due to slab placement. In the submerged slab methods, 40 minutes are allotted for this element while in the flush slab repair method a total of 72 minutes is allowed. It should be noted that, even though for the 50-foot by 50-foot repair the slab sizes are increased to 8 feet by 8 feet, a total of 36 slabs will be required. The task of preparing a sufficiently smooth surface to meet Category A roughness criteria with 36 individual slab placements appears to be quite challenging. In addition to individual leveling of each slab, correct alignment, both longitudinally and transversely, must be maintained to prevent congestion in the repaired surface. Thus, for the flush slab on debris and flush slab on select fill without a special leveling course, the respective rates of replacement are 8.93 and 8.33 ft^2/min. Total respective times of repair are 280 and 300 minutes. If a leveling course is used in the select fill method, the total repair time and repair rate are 310 minutes and 8.07 ft^2/min, respectively.

An examination of the task elements for the various precast slab repair methods reveals that the overall repair involves several main efforts: preparation of the backfill material to receive the slab, placement of the slab, and placement and curing of the rapid set concrete grout. Obviously the polymer concrete cap on debris method requires the least time of backfill preparation. In the German repair method, the reported time to initiation of slab placement was 105 minutes. The similar time frame, i.e., time consumed in preparation of the backfill to receive slabs for the 20-foot by 20-foot repair methods, ranged from 90 minutes for the submerged slab on debris repair to 115 minutes for the flush slab on select fill with a leveling course. Therefore, it appears that all of these methods would be competitive within that extent of repair. The backfill preparation time for the comparative repairs in the 50-foot by 50-foot crater ranged from 135 to 170 minutes with the flush slab repair methods obviously requiring the longer backfill preparation times. As was noted earlier, obviously, the placement time for the flush slab repair would be higher than for the submerged slab repair due to the requirement for leveling and alignment. Significant factors in the precast slab repair methods are time for placement and curing of the rapid-set concrete. In all methods, the curing time is the predominant time consumer (60 minutes). For the 50-foot by 50-foot repairs the total time of placement and curing ranged from 70 to 80 minutes. Thus, the significance of the time allotment for curing alone is obvious.

On the basis of total time of repair, the submerged slab in an irregular opening method appears to be competitive with the repair involving a submerged slab in the 50-foot by 50-foot opening. However, due to the smaller repair

area, the rate of repair for this method is the lowest, i.e., 7.85 ft^2/min. This approach to repair appears to have potential; however, the multiplicity of functions, especially the need for a high degree of compaction in the nonslab area, will make this type of repair somewhat complicated and will require extensive coordination.

Apparently, then, the three most effective methods for use in crater repair are: slabs alone without load transfer, slabs with load transfer and a concrete cap, and slabs with load transfer and no concrete cap. The use of slabs alone, i.e., the German method, appears to be the most rapid repair method based on reported results with a smaller crater. When it is used on a larger crater, the difficulties inherent in obtaining a sufficiently smooth operating surface are apparent, and the time involved would be practically the same as that involved in the flush slab repair. The primary difference between the two methods is that a load transfer grout is applied in the flush slab method. Although this element requires additional time for placement and curing, it may be a significant factor, under traffic, in maintaining slab position and in minimizing surface distress in the form of slab cracking, differential settlement, and development of surface unevenness.

The submerged slab repair method, from a time-of-repair view, requires more time than the polymer cap on debris or the German method; however, it is more rapid than the flush slab method and offers the potential of providing a smooth, finished repair surface that will meet desired roughness criteria. In addition, slab placement time is less than for the other precast slab repair methods, and the submerging of slab modules in concrete matrix appears to offer an inherently more stable layer.

It should be noted, however, that in this repair method in which rapid setting or polymer type concrete is anticipated for use, the time element estimates are predicated on achieving the placement and cure times indicated; therefore, any significant variation in actual times required and estimated time elements could be detrimental to overall time of repair.

2. Structural Analysis

A summary of slab thickness values developed from the theoretical analyses using the layered elastic program along with calculated values of vertical stress on the backfill are shown in Table 20. The structural analyses were based on the use of debris backfill with an assumed strength of 4 CBR. This approach was used as the worst-case condition. Also, with a layered elastic program, uniform support under the layer must be assumed, and this condition may not always be the actual case. Use of granular backfill would offer an alternate solution; however, in order to provide uniform support it must be well compacted and grouted, and a bedding layer may be required. For the layered elastic analysis, the mechanistic system also involves the assumption of a homogeneous layer with complete load transfer.

The results of the stress analysis indicate that the composite slabs require the thinnest sections (4.6 to 6.6 inches), while the plain portland cement concrete slabs require the thickest sections (7.4 to 9.4 inches). The thickness requirements for the fibrous concrete fall between these values (5.3 to 7.3 inches). These thickness requirements are obviously a reflection of the

TABLE 20. SUMMARY OF THEORETICAL LAYER AND SLAB THICKNESS DATA AND VERTICAL STRESS CALCULATIONS (WITH LOAD TRANSFER).

Method	Slab Type	Total Layer Thickness in.	Rapid Set Concrete Cap Thickness in.	Slab Thickness in.	Vertical Stress On Backfill, psi
Submerged slab	PCC	9.4	2.0	7.4	8.5
Flush slab	PCC	9.4	--	9.4	8.5
Submerged slab	Composite	6.6	2.0	4.6*	12.5
Flush slab	Composite	6.6	--	6.6**	12.5
Submerged slab	Fibrous concrete	7.3	2.0	5.3	9.8
Flush slab	Fibrous concrete	7.3	--	7.3	9.8

* 3.5-inch PCC upper; 1.1-inch polymer concrete lower.

** 5.5-inch PCC upper; 1.1-inch polymer concrete lower.

stiffness of the layer and of the flexural strength of the various materials comprising the concrete slabs. The theoretical slab thickness values also vary with repair type by 2 inches, depending on whether the submerged slab or flush slab concept is being considered. While these analyses reflect hypothetical structural concepts, the actual performance to be obtained in field evaluation also depends on certain practical considerations. For example, will the fast-setting concrete used in the cap repair actually be 2 inches thick? Will it reach desired strength levels? Will the repair reflect a monolithic structure with load transfer? Will the finished product perform like individual slabs? The static analysis must be evaluated, therefore, primarily as an initial basis for actual design of a working slab, and some conservatism should be incorporated into the final design. It would appear, therefore, that as a starting basis for final design, the average thickness values for composite, fibrous concrete, and portland cement concrete, would be about 5, 6, and 8 inches, respectively.

An examination of values of the calculated vertical stress on the debris fill indicates that, for the continuous type of repair, the stress levels would be within tolerable limits. For conventional pavements, it is generally desirable to maintain stress levels under about 10 psi for high-volume traffic structures. Therefore, for the limited traffic values and temporary repair involved, it would appear that acceptable field performance will be achievable.

A summary of slab thickness and vertical stress values determined for the 6-foot by 6-foot slab with no load transfer is shown in Table 21.

TABLE 21. SUMMARY OF LAYER AND SLAB THICKNESS AND VERTICAL STRESS DATA (WITHOUT LOAD TRANSFER).

Repair Type	Vertical Stress On Backfill	Slab Thickness in.
German slab on granular fill	78.0	6.0
German slab on debris backfill	44.8	7.7
6-foot by 6-foot composite slab on debris	50.0	5.1
6-foot by 6-foot fibrous slab on debris	45.3	6.5

Based on a comparison with the German slab on granular fill, the 6-inch-thick slab is estimated to impart a vertical stress of about 78 psi on the granular fill. In order to meet stress requirements in the portland cement concrete, a thickness of 7.7 inches is indicated if the slab is used on debris backfill. Due to the softer underlying material, i.e., debris, the resulting vertical stress is reduced to 44.8 psi, although deflection would probably be large. For composite and fibrous concrete slabs on debris, the respective slab thicknesses indicated are 5.1 and 6.5 inches and 50.0 and 45.3 psi. These stresses appear to be excessively high in order for the underlying material to sustain any large number of aircraft traffic repetitions. However, conventional pavement analytical methods do not address aircraft traffic repetitions on short blocks of this type. One approach using static analysis and bearing capacity formulas for building foundations may provide some measure of the ultimate load that may be applied to the soil. For this approach, some assumptions must be made concerning the fill material. For example, if it is assumed that the granular fill is a noncohesive material having a density of 130 pounds per cubic foot and an angle of internal friction of 45 degrees, Terzaghi's method may be used for local shear following the equation

$$q_{ult} = 0.4 \gamma B N_\gamma$$

where

q_{ult} = ultimate bearing capacity

γ = soil density

B = length of slab side

N_γ = bearing-capacity factor

The ultimate bearing capacity for the granular material is calculated to be 81.6 psi. This implies that under the static loading of a C-141 some local settlement would occur, possibly resulting in unevenness of the repair surface.

For the debris backfill, if it is assumed that the soil is a soft, purely cohesive material having an apparent cohesion, c, of about 8 psi, then the Terzaghi bearing-capacity formula for this situation is

$$q_{ult} = 1.3 N_c$$

where N_c is a bearing-capacity factor. Based on this assumption, the ultimate stress applicable to the backfill would be 59.3 psi. Therefore, it would

appear that under the condition of debris backfill the static load under any slab could approach the ultimate soil-bearing capacity, and again some deformation could occur.

3. Summary

From the data presented in the time and structural analyses, the precast slab crater repair method that identifies as optimum with respect to utilization of time, materials, and potential performance is one involving slabs with load transfer. Either the submerged slab or flush slab methods involve load transfer; however, the submerged slab method appears to be superior from the properties of smoothness of the finished repair and the potential difficulty involved in leveling slabs for large crater repair with the flush slab method. Repair methods in which no load transfer is involved appear to offer the potential for development of surface roughness due to slab settlement; however, this aspect should be investigated.

Since the thickness values for the different slab types were developed based primarily on the structural characteristics of the material composing the slab, the layered elastic and the finite element approach specified essentially similar values. Specific designs for portland cement concrete and fibrous concrete slabs are presented later in this report. A modified version of the design of the German slab is also presented for future field testing.

SECTION IV

CONCEPTS, CONCLUSIONS, AND RECOMMENDATIONS

A. PROPOSED TEST CONCEPTS

Based on this study, it is proposed that AFESC pursue further field evaluation of the precast slab repair methods in the following priority: submerged slab, flush slab, and the German repair method. Also consideration should be given to evaluating the repair method involving submerged slabs in an irregular pavement opening. For these tests several experimental slab designs have been developed.

1. Conventional Concrete Slab

The structural analysis presented earlier provides baseline information for final development of the structural design of a conventional concrete slab for use in field testing. While static load analysis is useful in developing a common theoretical basis for comparison of material response, the design of specific types of slabs that will be subject to aircraft traffic loadings must incorporate concepts that evolve from actual performance. Therefore, the basis of the design of the conventional concrete slab was rigid pavement design methodology (Reference 9). In the design, it was assumed that the use of a structural cap may not add significantly to the slab performance. This assumption was based on the premise that, due to irregularities in leveling, the actual cap thickness would vary from 1 to 3 inches, and at least until the concept could be evaluated in actual field tests that it would not be incorporated into design. Design for both F-4 and C-141 aircraft were evaluated; however, due to the magnitude of loading, the C-141 is the controlling aircraft category. Specific design parameters used were: C-141 aircraft with a gross weight of 320,000 pounds. Since the aircraft traffic will be somewhat confined due to the narrow operating surface, design was based on channelized traffic. In conventional design, channelized traffic is considered to be a Type B traffic area. Modulus of rupture for the concrete was assumed as 700 psi, and modulus of soil reaction for the backfill was assumed as 100 pci. Based on these parameters, a standard section thickness (t_{std}) (5000 coverages) was established as 13.7 inches. This value was then adjusted for a traffic level of 70 coverages for a C-141. For this adjustment a nonconservative statistical expression was used since it was desired that the slab weight be minimized.* The expression for adjusted thickness (t_{adj}) is: $t_{adj} = (0.1553 \log \text{coverages} + 0.5027)t_{std}$. The adjusted section thickness was 10.8 inches, which was rounded to 11 inches. A second adjustment was then made to the thickness value based on a study in which relationships were established between initial slab thickness and slab deterioration under traffic (Reference 10). Whereas in conventional pavement design initial cracking is considered to portend failure, it was felt that the crater repair could undergo considerable cracking

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* Comments to OCE about TM 5-824-3/AFM 88-6 (Rigid Pavement for Airfields other than Army) by R. S. Rollings, U. S. Army Engineer Waterways Experiment Station, 1981 (See Reference 9).

and, with maintenance, remain serviceable for the anticipated traffic. Therefore, assuming a shattered slab condition, the thickness value was reduced by 30 percent to 7.7 inches. The final design was rounded to 8 inches.

The basic slab shape was assumed to be square. This configuration is optimum with respect to handling characteristics in that one forklift may conveniently handle one slab. Using rectangular slabs would be more complicated and would require large equipment and more complex handling procedures.

In determining actual slab dimensions, two considerations must be evaluated: slab response under loading and total slab weight. Concepts on which slab reaction to loading are based assume that bending is induced in order for the slab to assume the stresses. This type of reaction would not occur in a short block, for example, which would essentially not bend and induce high surface stresses in the subgrade or debris backfill. The dimensional criteria for bending are that the minimum slab dimension must be equal to or greater than 3ℓ where ℓ is determined by the expression

$$\ell = \frac{E\,h^3}{12(1 - \quad)K}$$

where

ℓ = radius of relative stiffness,

E = modulus of elasticity,

h = slab thickness,

μ = Poisson's ratio,

K = modulus of soil reaction.

For the design parameters previously established, the values of ℓ and 3ℓ are 36.5 inches and 109.5 inches, respectively. Based on these criteria, the minimum slab dimension to ensure bending would be 9.125 feet. In the interest of minimizing weight, slab dimensions were selected at 8 feet by 8 feet. For an 8-inch thick slab, the total weight, irrespective of reinforcing steel, would be approximately 6400 pounds.

A decision to incorporate some reinforcement into the design but to allow no further reduction in thickness was made to control cracking. The percent steel was estimated based on the amount that would normally be required when a reduction from the 11-inch design is allowed. Since there is no theoretical basis for determining percent steel, the amount and location were established somewhat arbitrarily. For a reduction to 8 inches and to 9 inches, the percent steel required is 0.400 and 0.175, respectively. To counteract stress concentrations caused by eccentric loading and nonuniform foundation support, it was determined that steel reinforcement should be placed in both directions and in the top and bottom of the slab. Therefore, the percent steel for one direction and one layer was established as a compromise between the values indicated, and the final design was set at about 0.25 percent. Based on this amount of steel,

the reinforcing mat design was established at use of Number 3 deformed reinforcing bars (ASTM A615-8, No. 3., Grade 40) at 6-inch maximum spacing on center with closer spacings at the edges of the slab. Since the slabs were designed for use in the submerged slab and flush slab repair methods, the final configurations also involved keyway side faces. The slab design is shown in Figure 26.

2. Steel Fiber-Reinforced Slab

The approach in designing the steel fiber-reinforced concrete slab also involved first developing a standard thickness (5000 coverages) and then allowing a reduction for design for 70 coverages (Reference 11). The standard thickness for this slab is 7.8 inches. Using a nonconservative approach, the reduction from this value is based on the following equation:

$$\% = 0.20 + 0.17 \log \text{coverages}$$

Based on this relationship, the standard thickness may be reduced by 48.6 percent. The reduced value of thickness for the fibrous concrete slab is 3.8 inches. For a slab of this type, a check must also be made for deflection. This estimated deflection value was 0.195 inches; however, the allowable deflection is 0.165. Thus, the design thickness was increased to 5.0 inches. Due to the thin section for this design, the slab lateral dimensions were set as 6 feet by 6 feet. The slab design is shown in Figure 27. Recommended design mixes for fibrous concrete are shown in Table 22. From Figure 27 it can be seen that a keyway has been incorporated into the slab design to facilitate load transfer.

3. 6-Foot by 6-Foot Portland Cement Concrete Slab with No Load Transfer

Design of a 6-foot by 6-foot reinforced concrete slab 6 inches thick was also developed to be used for evaluation of the German repair method in which no load transfer devices are used. This design is shown in Figure 28.

4. Lifting Devices

For this purpose, a commercially available lifting device is recommended. Positions of the device are shown for each slab design. Specific sizes and types of devices are indicated in each plan of test. The general type of device is similar to the Dayton T-1 Sure Grip® device, manufactured by the Dayton Sure-Grip and Shore Company. Lifting devices are identified by the T-1 designation along with slab thickness and lifting bolt diameter. For the three slab designs indicated, a 1 1/2-inch diameter bolt is required.

5. Screeding of Backfill

In past bomb crater repair tests, two approaches have been used in screeding of backfill material. For small, square-cut craters, a screed board suspended into the crater opening from rollers or skids that ride along the pavement surface has been used to level sand or fine aggregate material at a fixed distance below the pavement. For repairs involving large craters in which crushed aggregate is used to fill the entire crater to the surface, a long, heavy, metal screed, similar to a bulldozer blade, is pulled over the

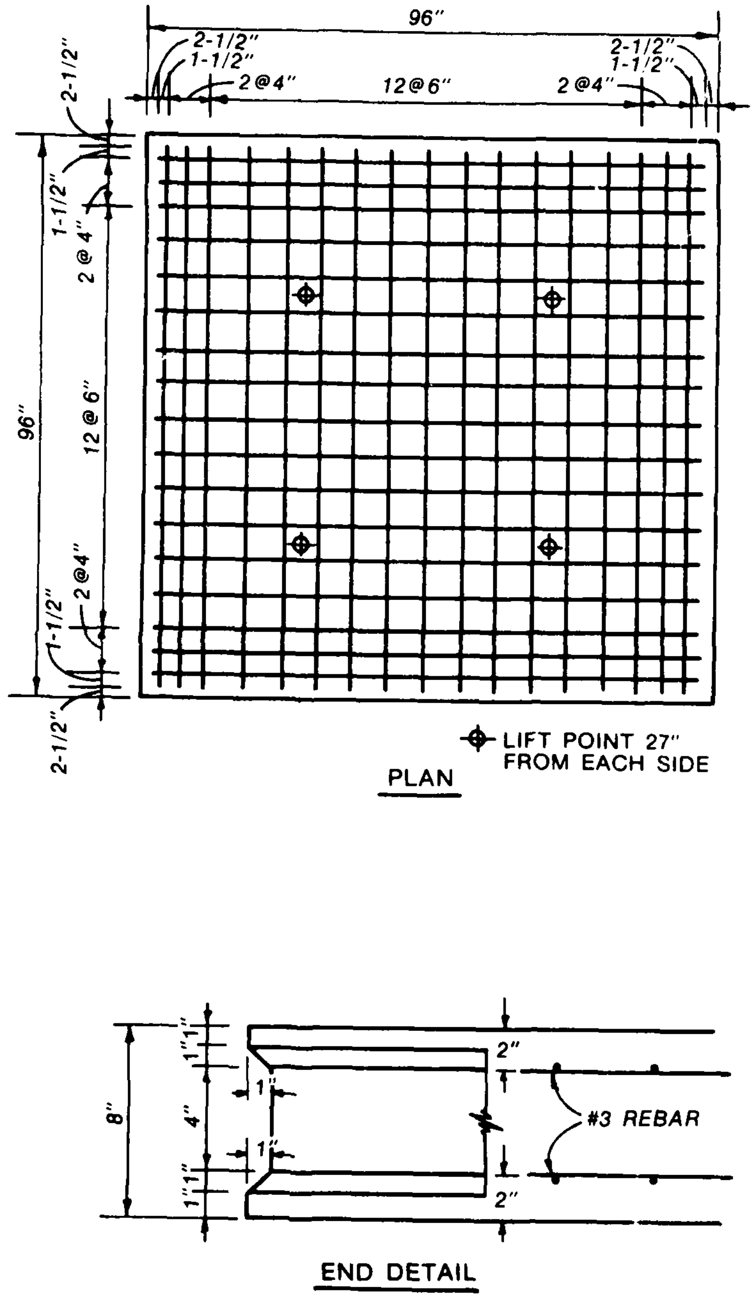

Figure 26. Design of 8-Foot by 8-Foot Reinforced Precast Slab.

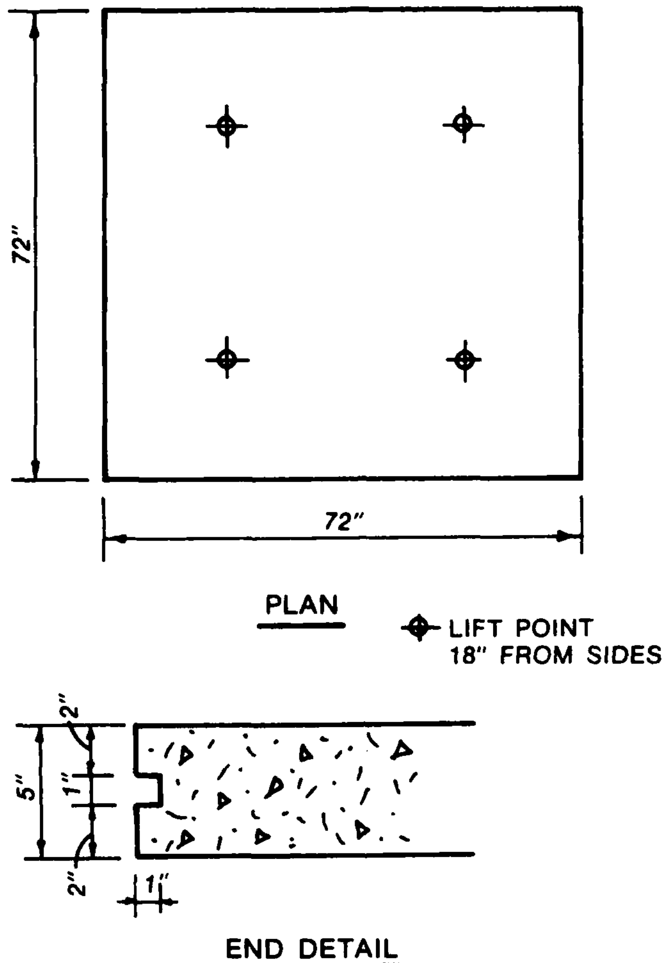

Figure 27. Design of Steel Fiber-Reinforced Slab.

upper surface. With the ends of the screed resting on the pavement surrounding the repair, a relatively smooth surface may be screeded. The former method may be used successfully for smaller crater repairs involving precast slabs. Whether the fill material is debris or select material, there should be placed on the surface of the fill a leveling course of sand or pea gravel. A screed suspended across the crater opening and pulled along by hand or equipment would prove satisfactory for such a repair. For large craters, it would probably prove impractical to construct a screed device that could be suspended across the entire opening. Therefore, two approaches are offered. In the first approach, a divider board (possibly 2 inches by 6 inches in cross section) could be placed across the center of the repair opening after the fill - select or debris - has been placed, dividing, for example, a 50-foot by 50-foot crater into two areas, each 25 feet by 50 feet. A suspension screed, similar to the type recommended for small crater repairs, could then be utilized to level a sand or pea gravel bedding course placed on the finished fill. A concept for such a screed is shown in Figure 29. In this case, the screed length would not exceed 25 feet. A second concept which should be

TABLE 22. TYPICAL FIBROUS CONCRETE MIXES.

Material	Saturated Surface Dry Batch Weight lb
Mix I	
Cement (type 1)	846
Fine aggregate (natural sand)	1700 (70%)
Coarse aggregate (3/8-inch maximum-size natural pea gravel)	728 (30%)
Fibers (round, 1 inch long bv 16 mils in diameter)	250 (2%)
Water	390
Air-entraining agent (5% air)	--
Mix II	
Cement (type 1)	517
Fly ash	225
Fine aggregate (natural sand)	1525 (55%)
Coarse aggregate (3/4-inch maximum-size crushed limestone)	1200 (45%)
Fibers (rectangular, 1 inch by 10 by 22 mils)	200 (1-1/2%)
Water	275
Air-entraining agent (4% air)	--
Set-retarding admixture	--
Mix III	
Cement (1 - P)	822
Fine aggregate (natural sand)	1593 (60%)
Coarse aggregate (3/8-inch maximum-size natural pea gravel)	1014 (40%)
Fibers	115 (1%)
Water	325
Air-entraining agent (5 percent air)	--

NOTES: Mix I resulted in slumps of about 4 inches and was used for manually constructed test pavements.

Mix II resulted in slumps of about 2 inches and was used for slip-formed 4- and 6-inch thick overlays.

Mix III resulted in slumps of about 4 inches and was used for manually constructed test pavements.

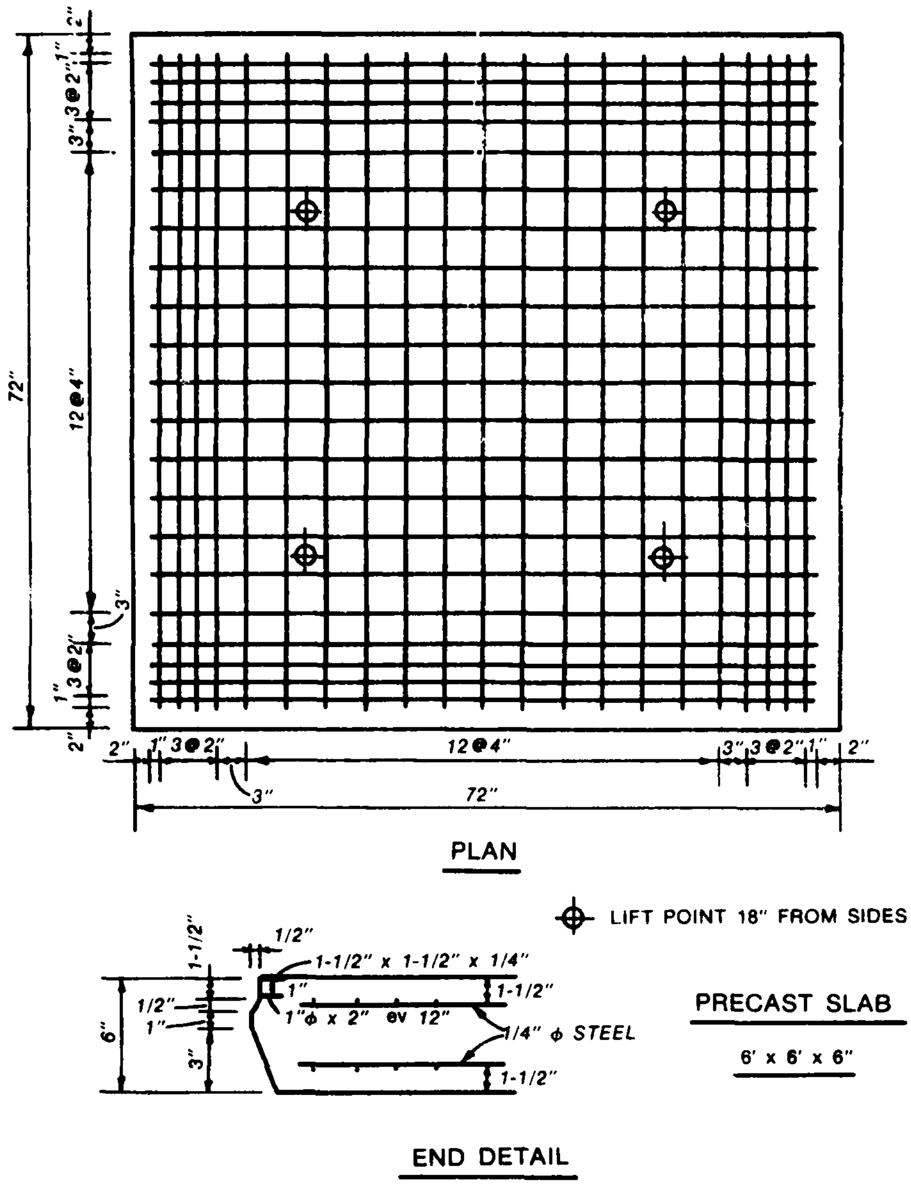

Figure 28. Design of 6-Foot by 6-Foot Reinforced Concrete Slab.

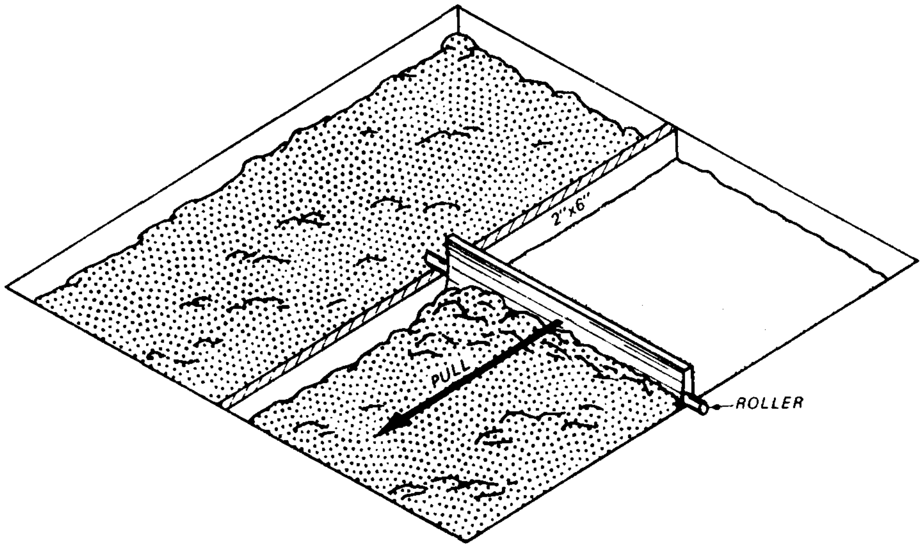

Figure 29. Suspension Screed.

evaluated would be to fabricate a blade device that could be attached to and extend laterally from the blade of a road grader. Such a device, no more than 10 feet long, could be fixed with the lower edge of the blade extension at any desired depth below the edge of the conventional grader blade. In use, the grader traveling on the pavement surface would traverse the length of the crater. The grader blade would be extended transversely, and the extension blade would screed the backfill at a predetermined distance below the pavement surface. Depth control could be maintained by holding the conventional blade minimally above the pavement surface during the screeding pass. This concept is shown in Figure 30. After the first screeding pass, a line of slabs could be placed which would then provide a riding surface for the grader on the next screeding pass. Alternate efforts of screeding and slab placement would provide means of advancing lines of slabs across the crater opening. Use of two such devices simultaneously could allow slab placement from opposite sides of the crater opening.

6. Test Plans

Test plans were developed for field tests to be conducted in a 20-foot by 20-foot crater facility for the submerged slab and flush slab methods utilizing the 8-foot by 8-foot by 8-inch slab. These test plans which are designed primarily for structural evaluation of the slab are presented in Appendixes A and B. A test plan was developed for evaluation of time requirements for the various repair tasks for a 50-foot by 50-foot repair. This test plan is presented in Appendix C.

B. CONCLUSIONS

The following conclusions are based on analysis of the various bomb crater repair methods using precast concrete slabs:

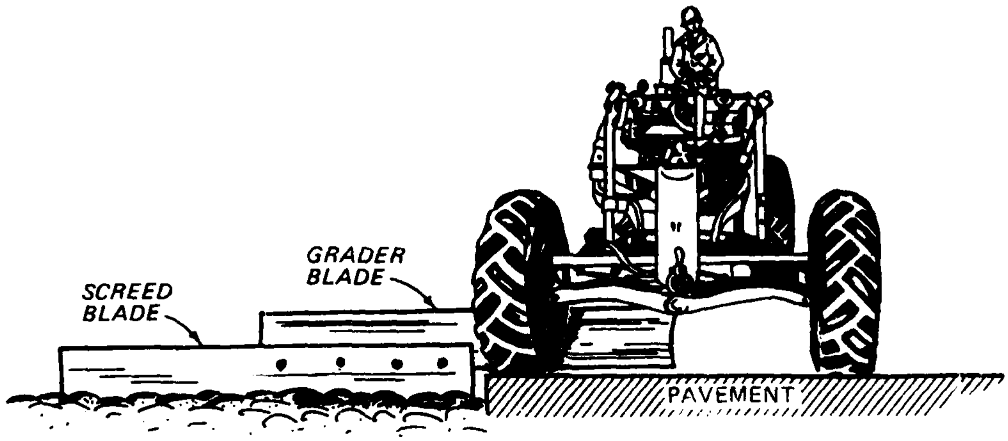

Figure 30. Grader Blade Extended Transversely and Extension Blade Screeding the Backfill.

1. The use of precast slabs in bomb crater repair is feasible; however, field testing must be conducted for verification and/or modification of certain critical procedures to ensure that the repair methods are competitive.

2. Based on time analysis alone, the most competitive repair method is the German method, followed by the submerged slab method and the flush slab repair method; however, it must be noted that these and all time estimates are based on essentially idealized conditions of manpower, material, and equipment resources.

3. Based upon projected performance under aircraft traffic, repair methods involving load transfer between slabs appear to be preferable to those in which there is no load-transfer mechanism.

4. The submerged slab concept has the advantage of providing the smoothest finished repair surface and appears to be the method with the best potential for future development.

5. The flush slab repair method, while feasible, has the disadvantage of requiring additional time to prepare a bedding surface and level slabs so that desired roughness criteria may be achieved. Again, one should be cognizant of the bases for all time estimates developed in this study.

6. Both repair methods may be accomplished on debris backfill if adequate load transfer is provided.

7. Structural performance of repair methods in which no load transfer is employed appears questionable on debris backfill but may give satisfactory performance on well-prepared granular backfill.

8. The feasibility of using large quantities of rapid-setting concrete must be established.

C. RECOMMENDATIONS

As a result of this study, the following recommendations are presented:

1. That AFESC conduct field tests in the small crater facility to evaluate structural response of repairs for the submerged slab, flush slab, and German repair methods using the designs provided herein and

2. That for those repair methods that prove to be structurally feasible, AFESC conduct field tests in the large crater facility to evaluate time requirements of the various tasks involved.

SECTION V

REFERENCES

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4. "USAFE: Improving Its Runway Damage Repair Capabilities," Aviation Week and Space Technology, pp. 62-63, 7 June 1982.

5. Rollings, Raymond S. and Chou, Yu T., Precast Concrete Pavements, MP-GL-81-10, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, November 1981.

6. Koninklijke/Shell Laboratorium, BISAR User's Manual: Layered Systems Under Normal and Tangential Loads, Amsterdam, Holland, July 1972.

7. Chou, Yu T, Structural Analysis Computer Programs for Rigid Multicomponent Pavement Structures with Discontinuities-WESLIQID and WESLAYER; Program Development and Numerical Presentations, TR-GL-81-6 (Report 1), U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, May 1981.

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9. Headquarters, Department of the Army, Rigid Pavement for Airfields Other Than Army, TM 5-824-3/AFM 88-6, Chapter 3, August 1979.

10. U. S. Army Corps of Engineers, A Method for Estimating the Life of Rigid Airfield Pavements, TR-4-23, Ohio River Division Laboratories, Cincinnati, Ohio, March 1962.

11. Parker, Frazier Jr., Steel Fibrous Concrete for Airport Pavement Application, TR-S-74-12, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, November 1974.

APPENDIX A

PLAN OF TEST, SUBMERGED SLAB CRATER REPAIR

(SMALL CRATER FACILITY)

(8-FOOT BY 8-FOOT BY 8-INCH SLAB)

PLAN OF TEST

SUBMERGED SLAB CRATER REPAIR

A. INTRODUCTION

Development of procedures for the rapid repair of bomb-cratered pavements has been the subject of intensive studies by the Air Force for several years. A number of tests were conducted by the Air Force Engineering and Services Center (AFESC) involving different materials and methods with varying degree of success. One such method involves the use of precast slabs.

A study was undertaken, therefore, to review past test results to determine specific precast slab repair techniques that offered the best potential and to further investigate and analyze these techniques. Results of this review have indicated that the most promising repair techniques have involved precast concrete slabs used in combination with fast-setting cement grouts. The primary considerations that appear to impact on the desirability of these methods are speed of repair, smoothness of the finished surface, and load-carrying capacity of the repair. One method which appears to offer potential, and the one with which this test will be involved, employs 8-foot by 8-foot precast slabs. In this repair method, the crater is first backfilled with debris so that when the slabs are placed, the top surface of each precast element lies about 2 inches below the surface of the surrounding pavement. Next, the void spaces between the slabs and over the slab surfaces are filled with rapid-setting cement grout to the surface of the old pavement, thus interlocking the slabs and forming a 2-inch thick grout cap flush with the old pavement surface.

For this investigation, after the crater repair has been completed, test traffic will be applied with both F-4 and C-141 load carts to evaluate the structural response under simulated aircraft loadings. Details of the test procedures are indicated below.

B. OBJECTIVE

The objective of this test is to evaluate means of rapid crater repair using precast concrete slabs and rapid-setting grout to provide a smooth repair surface.

C. SCOPE

This test involves repair of a simulated bomb crater using precast slabs with a thin concrete cap and evaluation of the performance of the repair under accelerated test traffic. It includes positioning of the slabs on a prepared clay bed and sand leveling course as well as placement and curing of the grout cap. Test traffic will be applied with C-141 and F-4 load carts. Primary variables to be evaluated include time of completion of each phase of the test, expenditures of manpower and equipment, difficulties encountered, and performance of the repair under simulated aircraft traffic.

D. TEST REQUIREMENTS

1. General Description

The test will be conducted in an existing concrete pavement site having a 17.5-foot by 17.5-foot square prepared pit. The crater area will be prepared to a uniform depth of 12 inches, and repairs will be made directly over the clay subgrade. The in-place clay soil will be processed to obtain a strength of about 4 CBR. A 2-inch sand leveling course will be placed on the clay. Four precast concrete slabs, each 8 feet by 8 feet square and 8 inches thick, will then be placed on the sand leveling course with 6-inch spacing between slabs. Bostik® 276 quick-setting cement grout will then be used to fill the total void spaces between and over the slabs up to the surface of the existing pavement. After the grout has cured, test traffic will be applied. A sketch of the desired configuration of the finished repair is shown in Figure A-1.

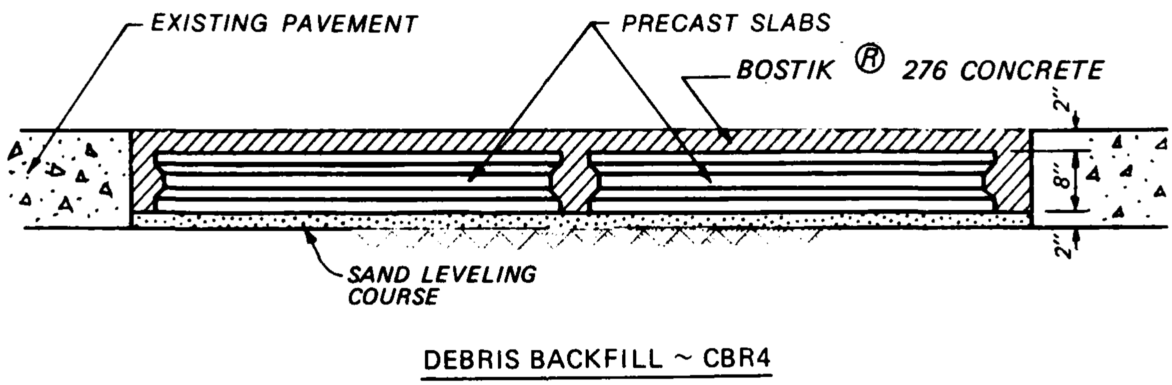


Figure A-1. Repair Concept.

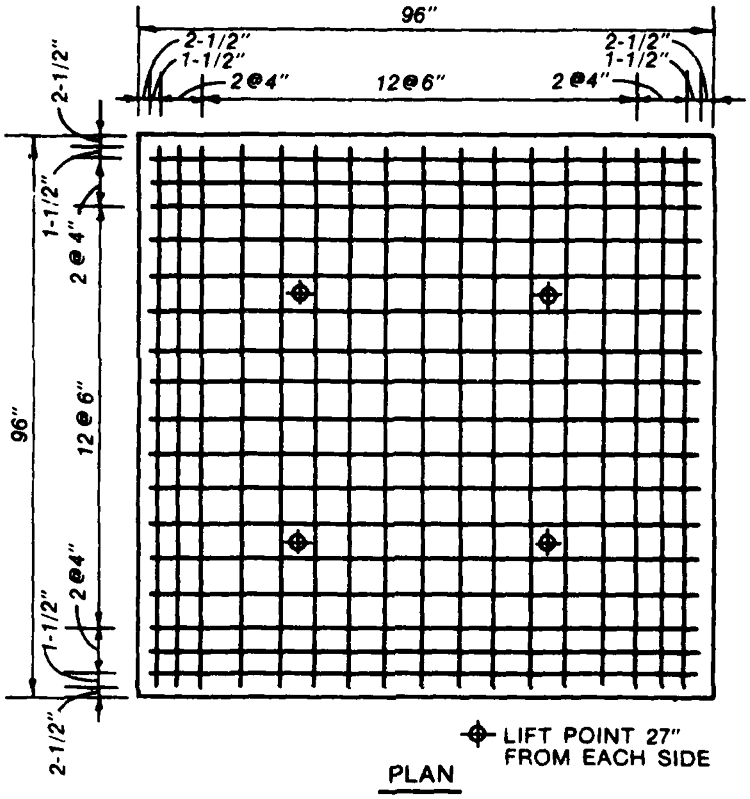
2. Resource Requirements

a. Materials

(1) Precast Slabs. Design of the precast slabs is shown in Figure A-2. Each slab will have nominal dimensions of 8 feet by 8 feet by 8 inches thick with keyway sides as shown. Each slab will have top and bottom reinforcement and will be equipped with four lifting devices located as shown. The recommended lifting device is the Dayton Sure-Grip® T-1 for an 8-inch-thick slab with a 1-1/2-inch pickup bolt. Four slabs will be required.

(2) Leveling Course. Approximately 4 cubic yards of sand will be required as a leveling course for placement of the precast slab. Any type of concrete sand will be satisfactory.

(3) Rapid Setting Concrete. The concrete material used to fill between slabs and to form the cap will be made with Bostik® 276 magnesium phosphate cement mixed with aggregate. The material will be mixed



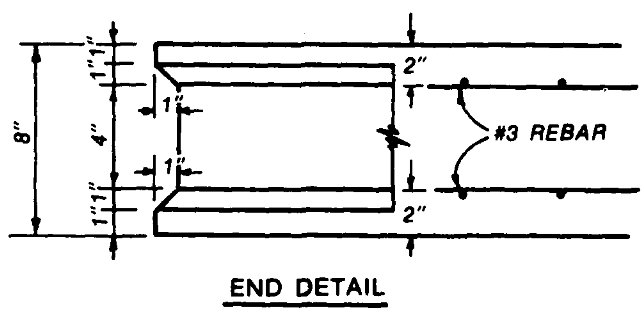


Figure A-2. Slab Design.

at the site with a mobile concrete mixer. The required quantities of material are 127 units of Bostik® 276 and 2.5 cubic yards (loose measure) of coarse aggregate. The mix will be prepared according to specifications indicated by the manufacturer's literature.

b. Task Elements, Equipment, and Manpower

(1) Task Elements and Equipment. Task elements with time allotments and equipment requirements are indicated on Table A-1. Time lines indicating estimated initiation and completion time of each task are shown in Figure A-3.

(2) Manpower. A crew of about eight personnel will be required. Of these, three should be equipment operators.

c. Cost Estimate

Precast slabs - 4 @ $150 each	$ 600
Concrete sand - 4 cu yd @ $15/cu yd	$ 60
Bostik® 267 - 127 units @ $32.20/unit	$5000
Aggregate for polymer concrete - 2.5 cu yd	
@ $15/cu yd	$ 38

3. Repair Procedures

a. Crater Preparation

It is desired that the foundation material in the crater represent the worst-case debris backfill condition. Therefore, crater preparation will, in general, consist of removing all nonrepresentative material and filling the crater with clay soil, similar to that in place, to a depth of about 12 inches below the surrounding pavement surface. It is desired that the basic crater opening be a square configuration, 17.5 feet by 17.5 feet on each side. If, after initial removal of existing material at the old crater site, the dimensions of the crater exceed 17.5 feet, then high-quality material such as crushed limestone or portland cement concrete should be used to close the opening to the desired configuration and provide stable edges for load transfer at the crater perimeter. Clay soil required to fill the crater to the desired elevation will be processed so that, when compacted, the soil strength will be about 3 to 5 CBR. For this facility, compaction may be accomplished with gasoline-powered tampers. The surface of the compacted clay should be leveled as closely as possible with hand tools. Next, a sand-leveling course should be placed on the clay. The sand should be consolidated with vibratory plate compactors so that the finished surface of the sand is about 10 inches below the surface of the surrounding pavement. Manual screeding of the sand will be necessary. After compacting, the sand surface will be ready to receive the precast concrete slabs.

TABLE A-1. TIME AND EQUIPMENT REQUIREMENTS, SUBMERGED SLAB, RAPID-SET CONCRETE CAP, DEBRIS FILL (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader/1 Grader/1 Dozer
Mark	10	Survey Equipment
Cut Concrete	10	2 Concrete Saws
Breakout Upheaval	10	2 Pneumatic Hammers
Remove Upheaval	20	2 Excavators
Place Debris Backfill	20	2 Dozers
Place Fine Aggregate	15	2 Trucks
Spread Fine Aggregate	10	1 Loader/1 Dozer
Place Slabs	15	2 Forklifts
Place Grout	20	2 Mobile Mixers
Cure Concrete	60	--
Sweep Repair Area	20	1 Sweeper

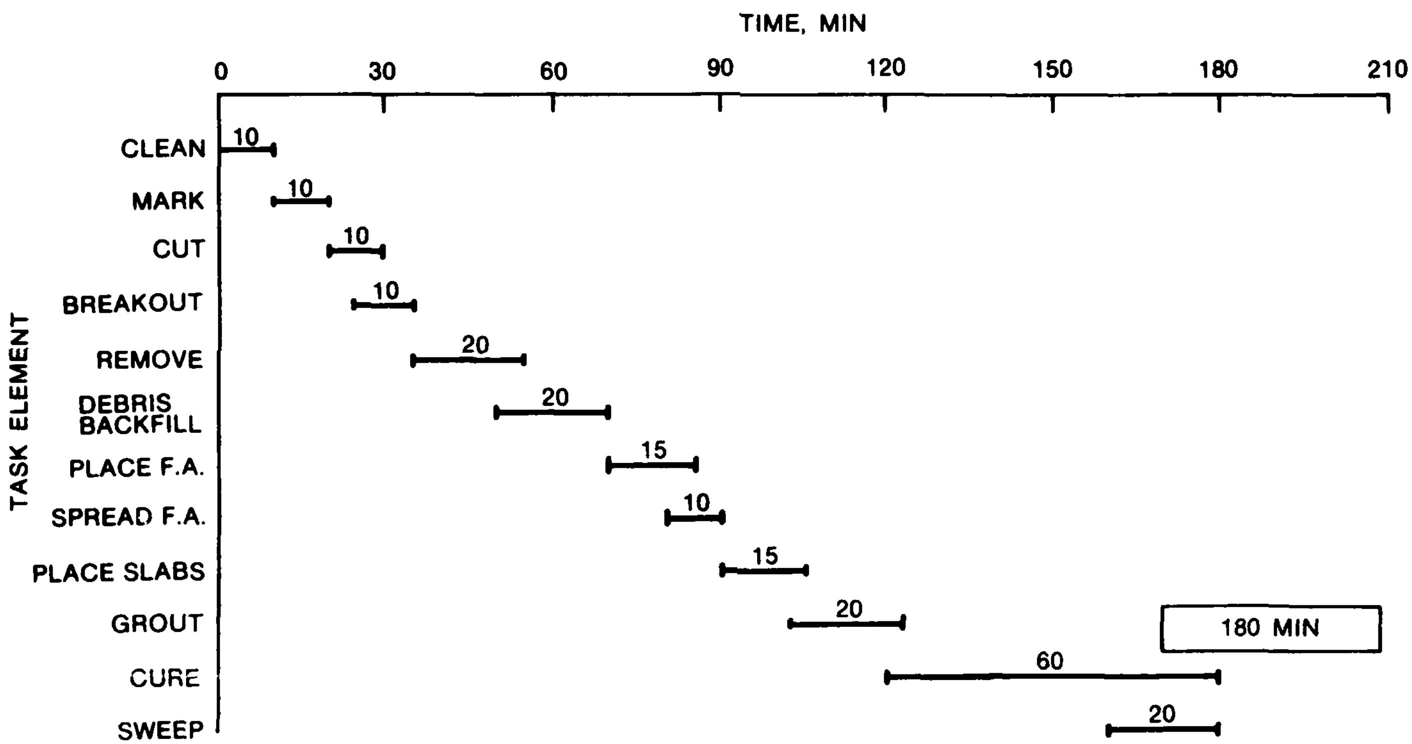


Figure A-3. Task Element Time Allotments.

b. Slab Placement

Four 8-foot by 8-foot precast slabs will be placed directly on the sand surface. Each slab will be equipped with quick-release devices. A forklift with sling may be used to lift and transport each slab. Slabs should be placed so that there is a 6-inch space between slabs and between the sides of the slabs and the sides of the crater opening. A layout of the slab configuration is shown in Figure A-4. In placing slabs, care should be taken to prevent undue disturbance to the sand surface.

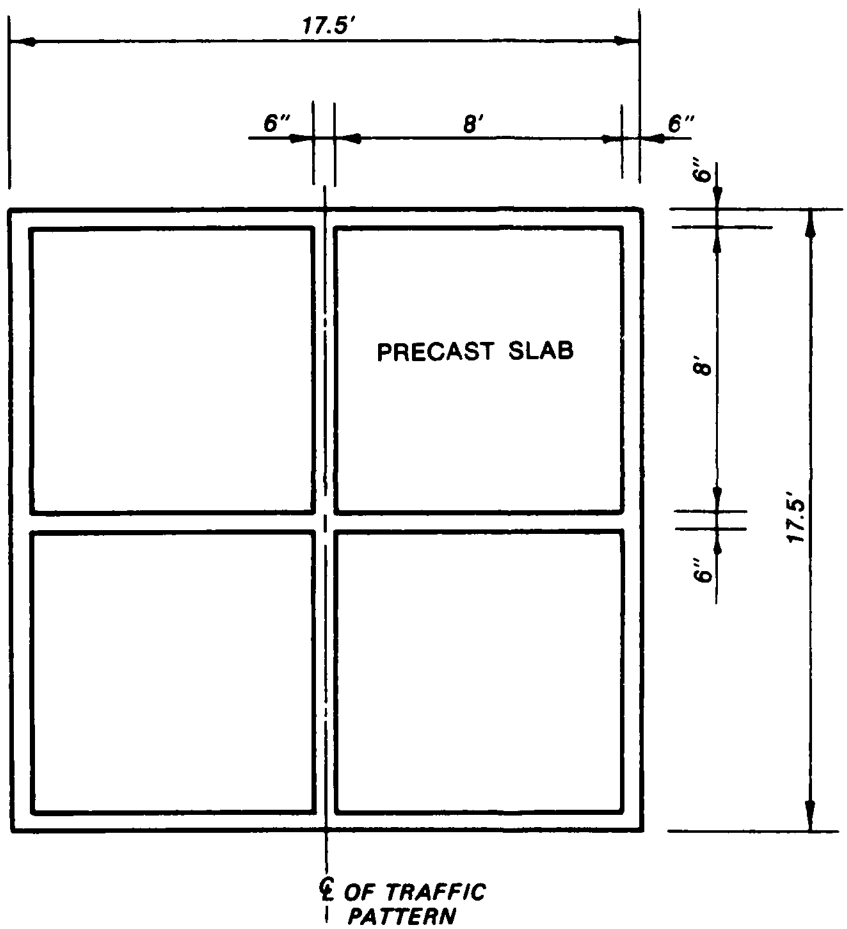


Figure A-4. Slab Placement Layout.

c. Rapid-Setting Concrete Cap

Bostik® 276 magnesium phosphate concrete shall be batched at the site using a portable mixer. The material shall be first poured into the void spaces between joints. Care shall be taken to ensure that all joints are filled. The concrete shall then be placed over the slab surface and the

crater filled to the surface of the old pavement. As the concrete is placed, it will be screeded to a smooth finish. A candidate screeding device is shown in Figure A-5. The pedestal unit is placed at the center of the repair, and the 14-foot screed is pulled around the repair surface in a circular motion to form a smooth surface. It is desirable that the finished surface meet Category A smoothness criteria for the F-4. Approximately 60 minutes should be allowed for the material to harden sufficiently for aircraft traffic.

4. Test Traffic and Failure Criteria

a. General

Test traffic will be applied with the F-4 and C-141 traffic carts. Minimum required traffic levels will be 150 coverages of the F-4 and 70 coverages of the C-141.

b. F-4 Traffic

F-4 traffic will be applied in an approximate normal distribution pattern over a 120-inch-wide lane. Traffic distribution and number of passes are shown in Figure A-6a. A total of 1440 passes will be required for 150 coverages. Position of the center line of the traffic lane on the test section is shown in Figure A-4. Traffic will be centered about a longitudinal joint line.

c. C-141 Traffic

C-141 traffic also will be applied along the joint in the pattern indicated in Figure A-6b. A total of 420 passes will be required for 70 coverages.

d. Failure Criteria

Failure criteria will be based on development of surface roughness. When surface roughness exceeds F4 Category C criteria as indicated in Rapid Runoff Repair Interior Planning Guidance for upheaval and/or sag, the pavement will be considered failed. Excessive spalling also will be considered a failure.

5. Maintenance Procedures

It is anticipated that this test item will deteriorate under traffic since it is designed to sustain minimum traffic repetitions. Distress such as deformation of the clay subgrade and cracking and spalling of the submerged slab system may result in large surface deformations exceeding the roughness criteria. Therefore, provision should be made for a repair team to be available during the test. The objective of the repair will be to fill depressions and restore the surface to an acceptable condition. The repair material will consist of cold-mix asphalt concrete. Periodic measurements should be made (supplemented by continuous visual monitoring) of the trafficked surface. When repairs are necessary, the surface should be swept clean of loose debris, the depressed areas filled in, and the asphaltic material compacted with a vibratory plate compactor. After the surface has been restored, test traffic should be resumed.

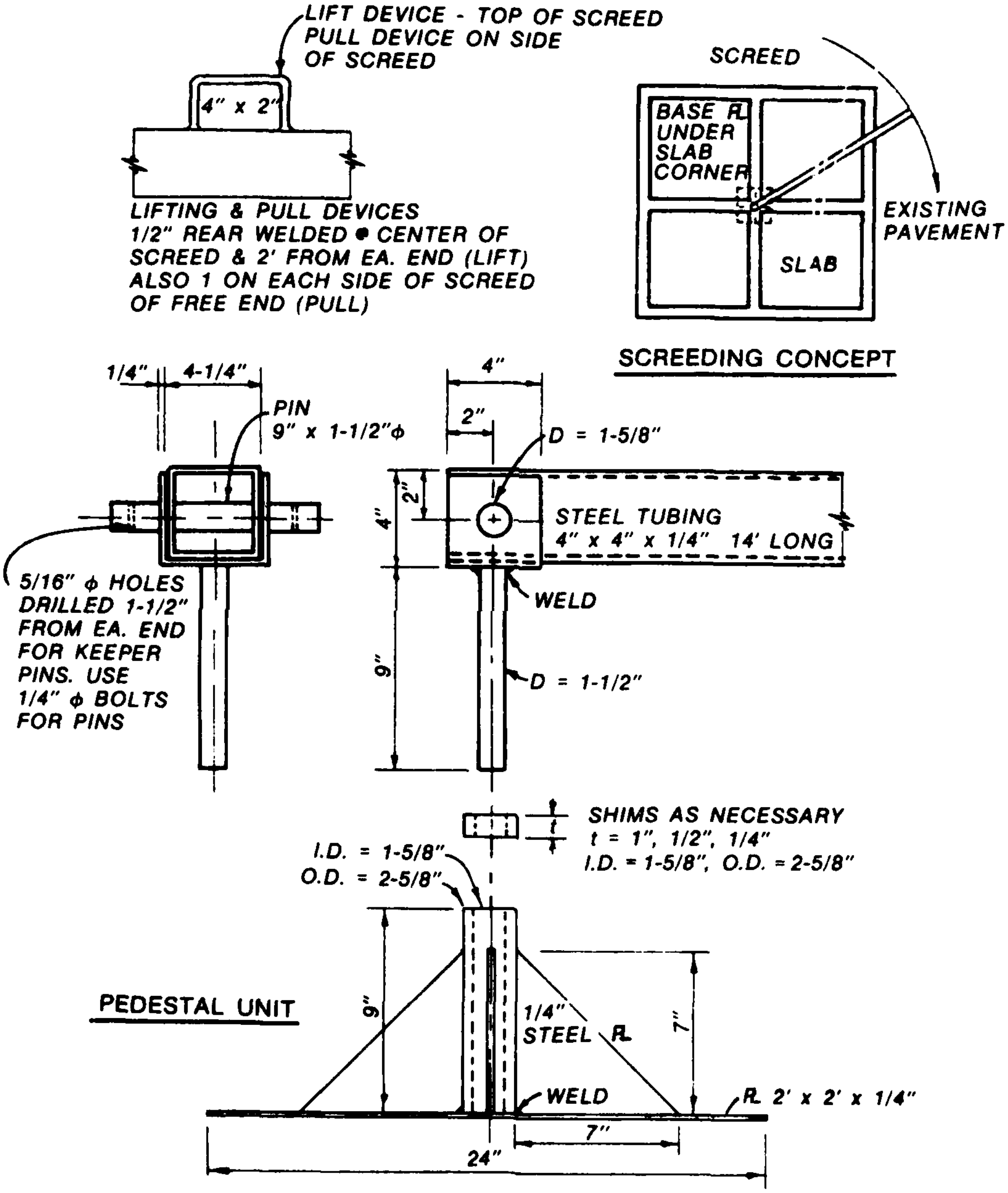
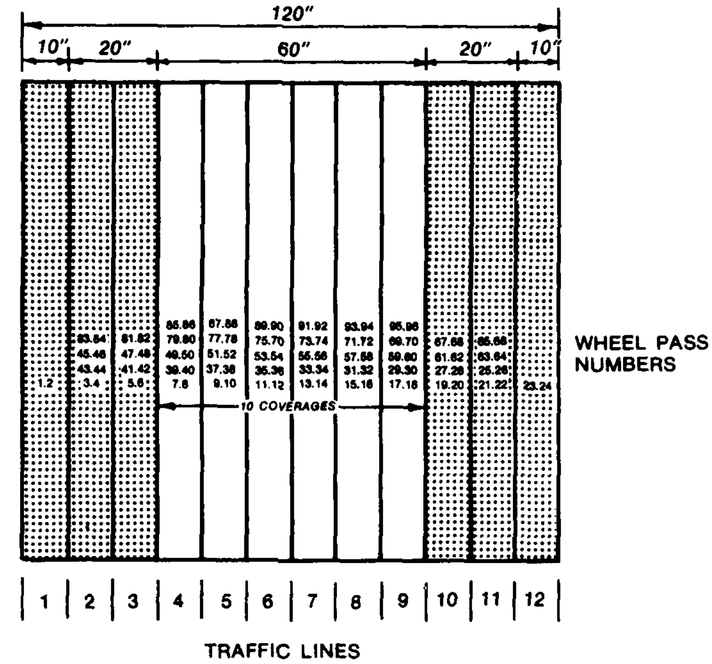
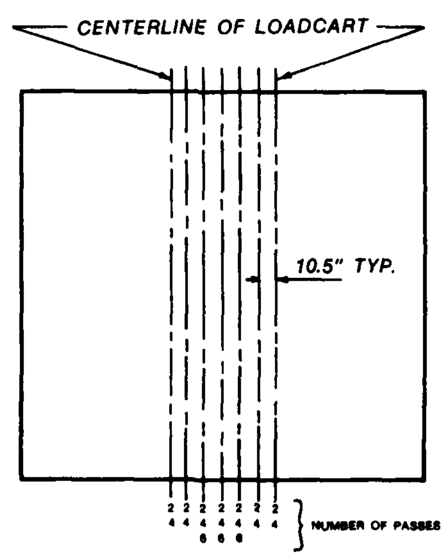


Figure A-5. Screeding Device.



a. TRAFFIC DISTRIBUTION PATTERN FOR THE F-4 LOAD CART



10 COVERAGES OF C-141 LOADCART

b. TRAFFIC DISTRIBUTION PATTERN FOR THE C-141 LOAD CART

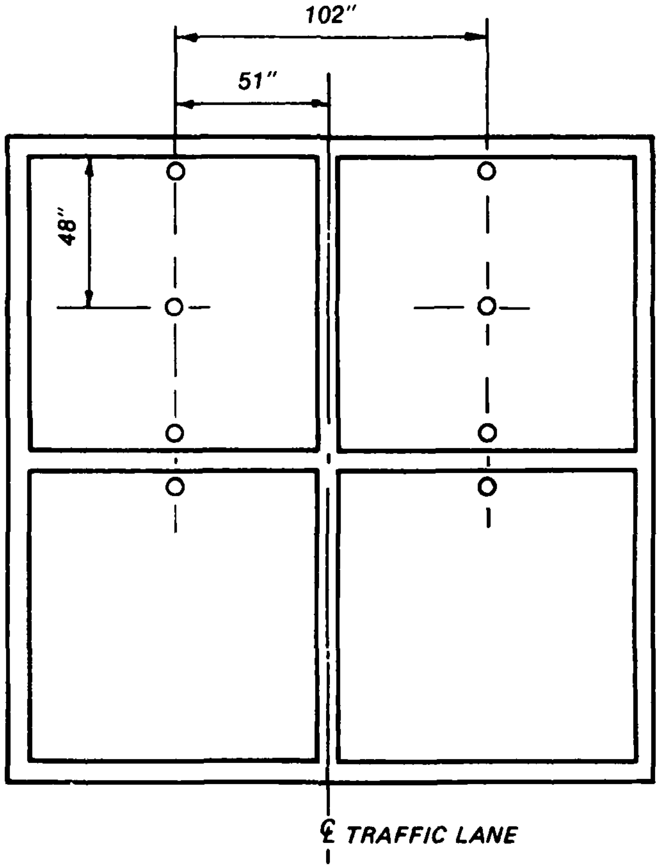
Figure A-6. Traffic Pattern.

6. Information and Data Collection

For each task element, time, equipment, manpower, and material expenditures, will be recorded. Data collection shall consist of visual observation of the performance of the slabs during traffic, measurement of changes in surface elevations at the corner and center of each slab, and responses of subgrade stress and slab strain. Traffic shall be stopped and data taken at 0, 10, 20, 40, 60, 80, 100, and 150 coverages of the F-4 cart and at 0, 10, 20, 40, and 70 coverages of the C-141 cart. If traffic is terminated at coverage levels below those indicated, data also will be recorded at that time. Surface elevation data should be obtained using an engineer's level; however, they also should be supplemented by making roughness measurements using the stringline method for comparison with established roughness criteria. Subgrade stress and slab strain data should be obtained by means of pressure cells and strain gages located as indicated in Figure A-7. Types and sources of pressure cells and strain gages potentially applicable are indicated in Table A-2 and Table A-3.

F. TECHNICAL REPORT

A technical report will be prepared, covering design and construction of the test repair area, conduct of the test (including time required for each task), requirements for equipment and manpower, evaluation of the repair effort, and results of traffic tests. Difficulties encountered during the test and recommendations concerning future testing and standardization of repair techniques also will be presented.



O INSTRUMENTATION POINT - AXIAL STRAIN GAGES @ 90° ON BOTTOM OF SLAB AND PRESSURE CELL IN TOP OF SUBGRADE

Figure A-7. Location of Response Instrumentation.

TABLE A-2. COMMERCIAL SOURCES OF SOIL PRESSURE CELLS.

Source	Telephone
Terrametrics, Inc. 16027 West 5th Ave. Golden, CO (Carlson Type Soil Stress Meters)	(302)279-7813
Kulite Semiconductor Products, Inc. 1038 Hoyt Ave. Ridgefield, NJ 07657 (Soil Pressure Cell Type 0234, Pressure Ranges 0-15, 0-50, 0-100 psi)	(201)945-3000
Gentran, Inc. 928 Thompson Place Sunnyvale, CA 94086 (Model GT601 or GT621)	(408)245-5501
Sensotec Div. 1400 Holly Ave. Columbus, OH 43212 (Model SA-E Soil Pressure Transducers, Pressure Ranges 0-20, 0-50, 0-600 psi)	(614)294-5436

TABLE A-3. COMMERCIAL SOURCES OF STRAIN GAGES.

Source	Telephone
Micro-Measurements PO Box 306 38905 Chase Rd. Romultus, MI 48174 (4-inch gages, Type EA-06-40 CBY-120 ED-DY-40 CBY-350 2-inch gages, Type EA-06-20 CBW-120 ED-DY-20 CBW-350)	(313)941-3900
BLH Electronics 42 Fourth Ave. Waltham, MA 02154 (Type FSQ2-300-355)	(617)890-6700

APPENDIX B

PLAN OF TEST, PRECAST SLAB FLUSH CRATER REPAIR

(SMALL CRATER FACILITY)

(8-FOOT BY 8-FOOT BY 8-INCH SLAB)

PLAN OF TEST

PRECAST SLAB FLUSH CRATER REPAIR

A. INTRODUCTION

Development of procedures for the rapid repair of bomb-cratered pavements has been studied by the Air Force for several years. A number of tests were conducted by the Air Force Engineering and Services Center (AFESC) involving different materials and methods, with varying degrees of success. One such method involves the use of precast slabs.

A study was undertaken, therefore, to review past test results to determine specific precast slab repair techniques that offered the best potential and to further investigate and analyze these techniques. The most promising repair techniques have involved precast concrete slabs used in combination with fast-setting cement grouts. The primary considerations that appear to impact on the desirability of these methods are speed of repair, smoothness of the finished surface, and load-carrying capacity of the repair. One method which appears to offer potential, and the one with which this test will be involved, employs 8-foot by 8-foot precast slabs. In this repair method, the crater is first backfilled with debris to such an elevation that when the slabs are placed, the top surface of each precast element lies flush with the surface of the surrounding pavement. Next, the void spaces between the slabs are filled with rapid-setting cement grout to provide interlock between the slabs and a means of load transfer.

For this investigation, after the crater repair has been completed, test traffic will be applied with both F-4 and C-141 load carts to evaluate the structural responses under simulated aircraft loadings. Details of the test procedures are indicated below.

B. OBJECTIVE

The objective of this test is to evaluate means of rapid crater repair using precast concrete slabs placed flush with the surrounding pavement and interlocked with rapid-setting concrete grout.

C. SCOPE

This test involves repair of a simulated bomb crater using precast slabs interlocked with concrete and evaluation of the performance of the repair under accelerated test traffic. This test will include positioning the slabs on a prepared clay bed and sand-leveling course as well as placement and curing of the grout. Test traffic will be applied with C-141 and F-4 load carts. Primary variables to be evaluated include time of completion of each phase of the test, expenditures of manpower and equipment, types of difficulties encountered, and performance of the repair under simulated aircraft traffic.

D. TEST REQUIREMENTS

1. General Description

The test will be conducted in an existing concrete pavement site having a 17.5-foot by 17.5-foot square prepared pit. The crater area shall be excavated to a uniform depth of 10 inches, and repairs will be made directly over the clay subgrade. The in-place clay soil will be processed to obtain a strength of about 4 CBR. A 2-inch sand leveling course will be placed on the clay. Four precast concrete slabs, each 8 feet by 8 feet square and 8 inches thick, will then be placed on the sand leveling course with a 6-inch spacing between slabs. Bostik® 276 quick-setting concrete will then be used to fill the total void spaces between the slabs up to the top surface of the slabs and the existing pavement. After the grout has cured, test traffic will be applied. A sketch of the desired configuration of the finished repair is shown in Figure B-1.

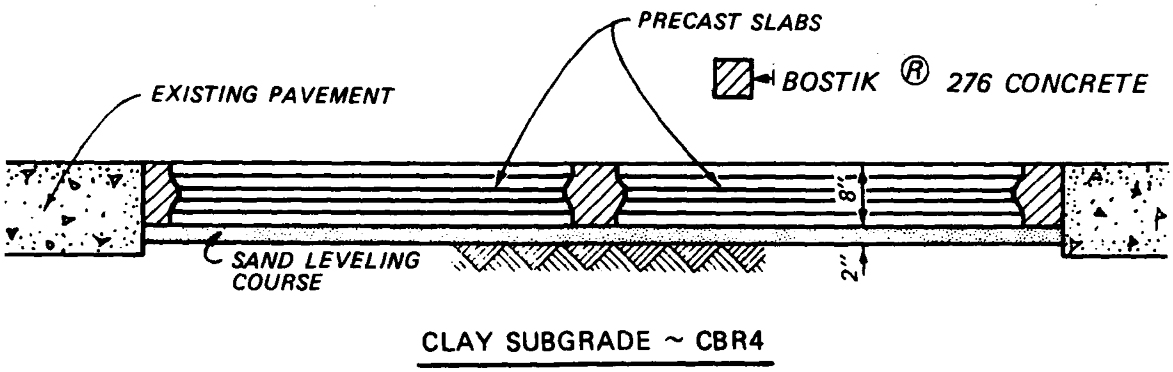


Figure B-1. Repair Concept.

2. Resource Requirements

a. Materials

(1) Precast Slabs. Design of the precast slabs is shown in Figure B-2. Each slab will have nominal dimensions of 8 feet by 8 feet by 8 inches thick with keyway sides as shown. Each slab will have top and bottom reinforcement and will be equipped with four lifting devices located as shown. The recommended lifting device is the Dayton Sure-Grip® T-1 for an 8-inch-thick slab with a 1-1/2 inch pickup bolt. Four slabs will be required.

(2) Sand Leveling Course. Approximately 4 cubic yards of sand will be required as a leveling course of placement of the slabs. Any type of concrete sand will be satisfactory.

(3) Rapid-Setting Concrete. The material to be used for fill between slabs will be grout made with Bostik® 276 magnesium phosphate cement mixed with aggregate. The material will be mixed at the site with a mobile concrete mixer. The required quantities of material are 55 units of Bostik® 276 and 1 cubic yard (loose measure) of coarse aggregate. The material will be prepared according to specifications indicated by the manufacturer's literature.

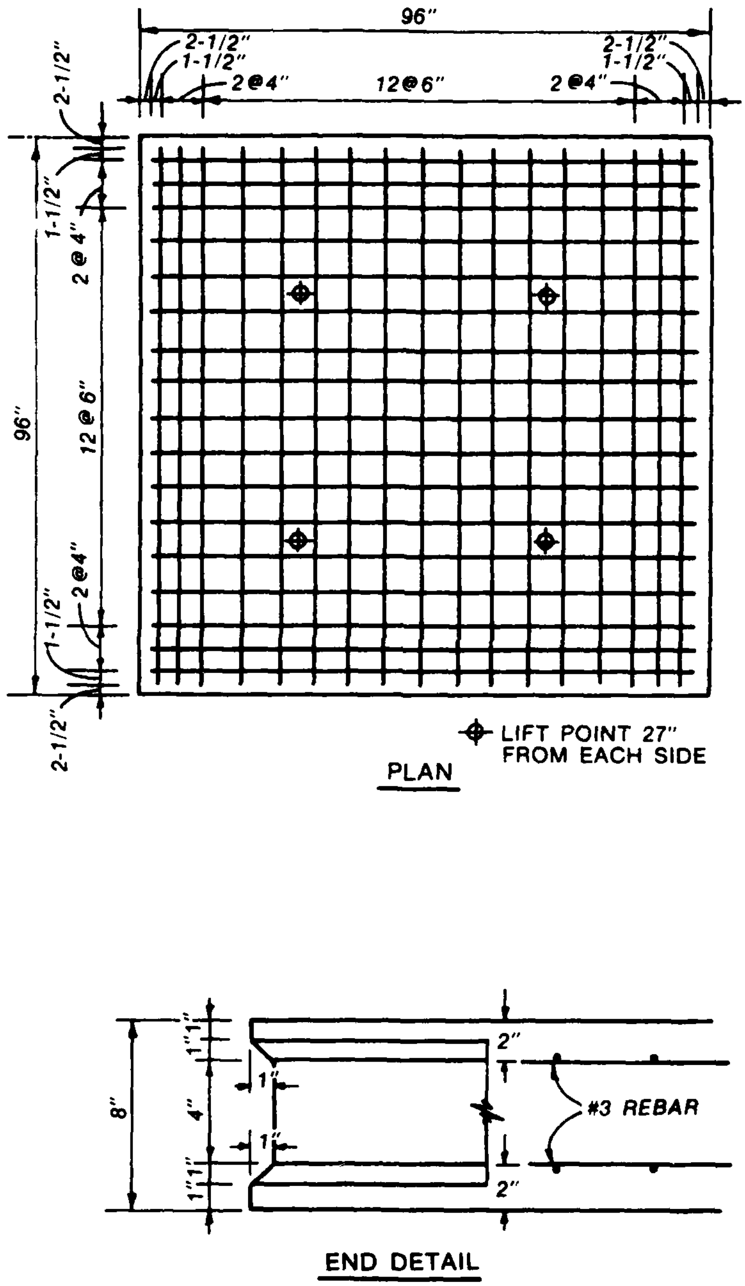


Figure B-2. Slab Design.

b. Task Elements, Equipment, and Manpower

(1) Task Elements and Equipment. Task elements with time allotments and equipment requirements are indicated on Table B-1. Time lines indicating initiation and completion time of each task are shown in Figure B-3.

(2) Manpower. A crew of about eight personnel will be required. Of these, three should be equipment operators.

c. Cost Estimate

Precast slabs - 4 @ \$150 ea	\$ 600
Concrete sand - 4 cu yd @ \$15/cu yd	\$ 60
Bostik® 267 - 56 units @ \$32.20/unit	\$1804
Aggregate for polymer concrete - 1 cu yd @ \$15/cu yd	\$ 15

3. Repair Procedures

a. Crater Preparation

It is desired that the foundation material in the crater be representative of the worst-case debris backfill condition. Therefore, crater preparation shall, in general, consist of removing all nonrepresentative material and filling the crater with clay soil, similar to that in place, to a depth of about 10 inches below the surrounding pavement surface. It is desired that the basic crater opening be a square configuration, 17.5 feet by 17.5 feet on each side. If, after initial removal of existing material at the old crater site, the dimensions of the crater exceed 17.5 feet, then high-quality material such as crushed limestone or portland cement concrete should be used to close the opening to the desired configuration and provide stable edges for load transfer at the crater perimeter. Clay soil required to fill the crater to the desired elevation shall be processed so that when compacted, the soil strength will be about 3 to 5 CBR. For this facility, compaction may be accomplished with gasoline-powered tampers. The surface of the compacted clay should be leveled as closely as possible with hand tools. Next, a sand leveling course should be placed on the clay. The sand should be consolidated with vibratory plate compactors and carefully screeded so that the finished surface of the sand is about 8 inches below the surface of the surrounding pavement. Manual screeding of the sand will be necessary. Prior to slab placement, elevation of the sand surface should be checked with a stringline.

b. Slab Placement

A layout of the slab configuration is shown in Figure B-4. In placing slabs, care should be taken to prevent undue disturbance to the sand surface. Four 8-foot by 8-foot precast slabs shall be placed directly on the sand surface. Each slab will be equipped with quick-release devices. A

TABLE B-1. TIME AND EQUIPMENT REQUIREMENTS, FLUSH SLAB REPAIR, RAPID-SET CONCRETE, SELECT FILL, NO LEVELING COURSE (20-FOOT BY 20-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	10	1 Loader/1 Grader/1 Dozer
Mark	10	Survey Equipment
Cut Concrete	10	2 Concrete Saws
Breakout Upheaval	10	2 Pneumatic Hammers
Remove Upheaval	30	2 Excavators
Place Select Fill	40	2 Dump Trucks/2 Dozers
Compact and Level Select Fill	20	1 Vibratory Roller
Place Slabs	30	2 Forklifts
Place Grout	10	1 Mobile Mixer
Cure Concrete	60	--
Sweep Repair Area	20	1 Sweeper

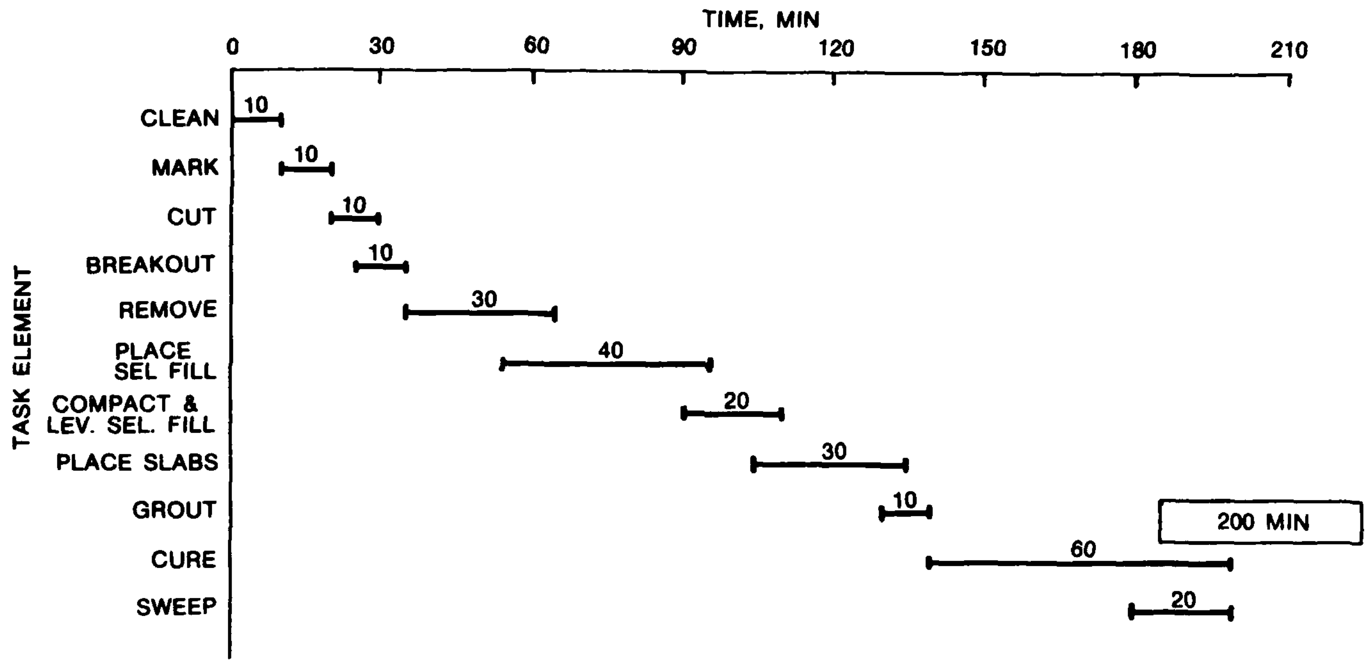


Figure B-3. Task Element Time Allotments.

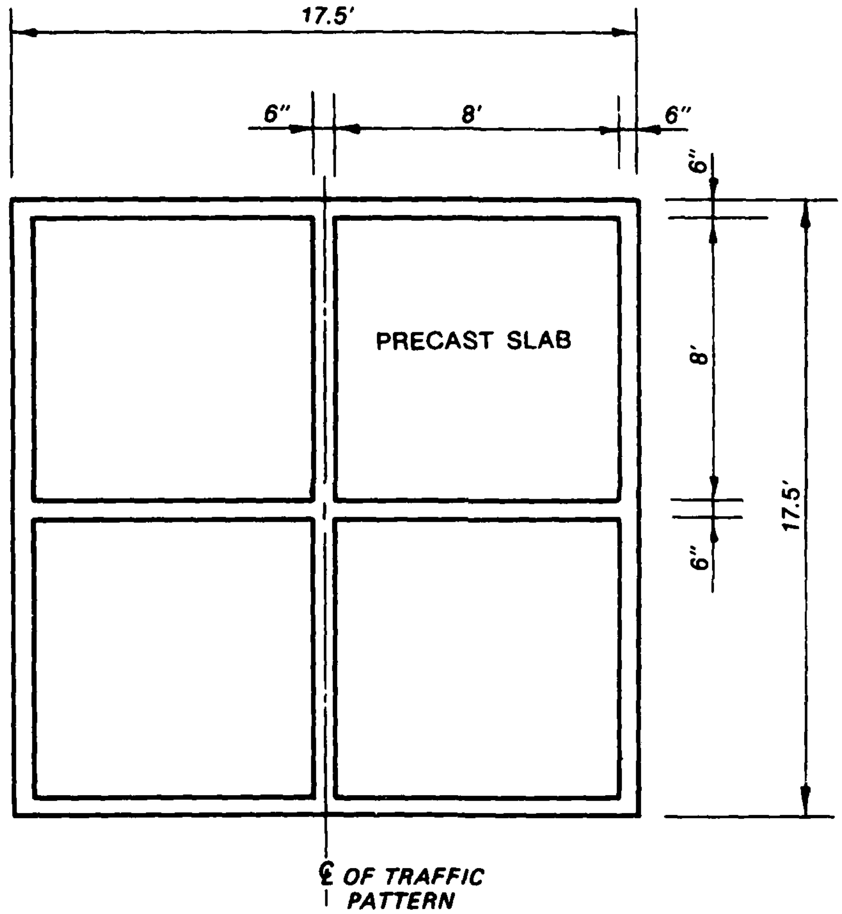


Figure B-4. Slab Placement Layout.

forklift with sling may be used to lift and transport each slab. Slabs should be placed so that there is a 6-inch space between slabs and between the sides of the crater opening. It is desirable that the plane of the slab surfaces meet Category A smoothness criteria for the F-4.

c. Rapid Setting Concrete

Bostik® 276 magnesium phosphate concrete shall be batched at the site using a portable mixer. The material shall then be poured into the void spaces between joints. Care shall be taken to ensure that all joints are filled to the surface of the slabs and existing pavement. As the concrete is placed in the joints, it shall be screeded to a smooth finish. Approximately 60 minutes should be allowed for the material to harden sufficiently for aircraft traffic.

4. Test Traffic and Failure Criteria

a. General

Test traffic will be applied with the F-4 and C-141 traffic carts. Minimum required traffic levels will be 150 coverages of F-4 and 70 C-141 coverages.

b. F-4 Traffic

F-4 traffic will be applied in an approximate normal distribution pattern over a 120-inch-wide lane. Traffic distribution and number of passes are shown in Figure B-5a. A total of 1440 passes will be required for 150 coverages. Position of the centerline of the traffic lane on the test section is shown in Figure B-4. Traffic will also be applied along the joint indicated in Figure B-5b.

c. C-141 Traffic

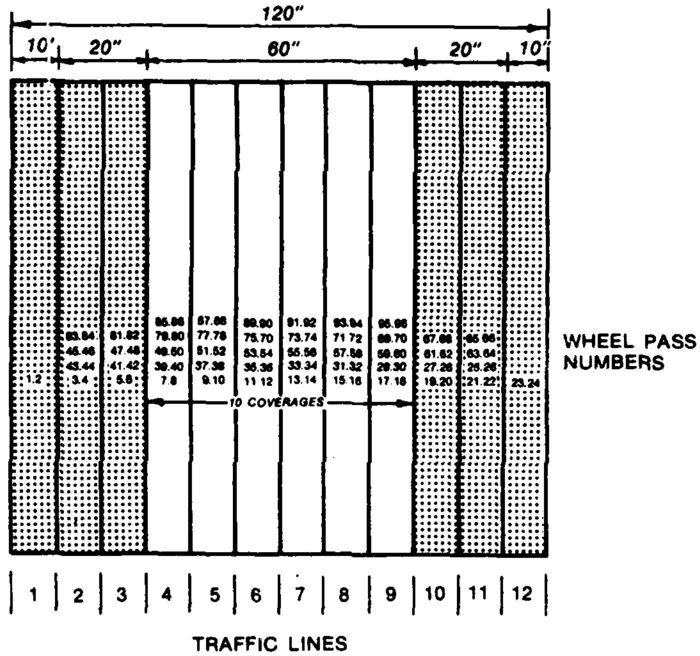
C-141 traffic also will be applied along the joint, in the pattern indicated in Figure B-6b. A total of 420 passes will be required for 70 coverages.

d. Failure Criteria

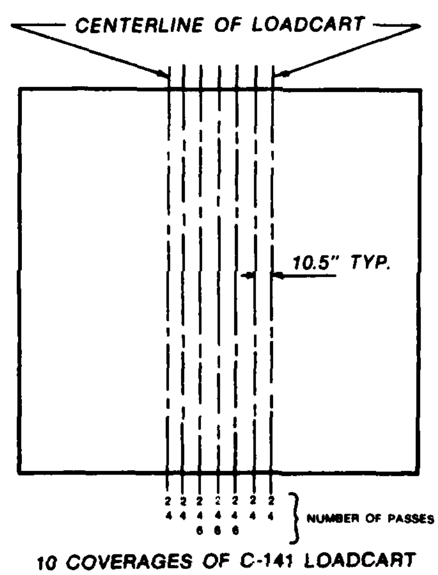
Failure criteria will be based on development of surface roughness. When surface roughness exceeds F-4 Category C criteria as indicated in Rapid Runoff Repair Interior Planning Guidance for upheaval and/or sag, the pavement will be considered failed. Excessive spalling also will be considered a failure.

5. Maintenance Procedures

It is anticipated that this test item will deteriorate under traffic since it is designed to sustain minimum traffic repetitions. Distress such as deformation of the clay subgrade and cracking and spalling of the interlocked slab system may result in large surface deformations exceeding the roughness criteria. Therefore, provision should be made for a repair team

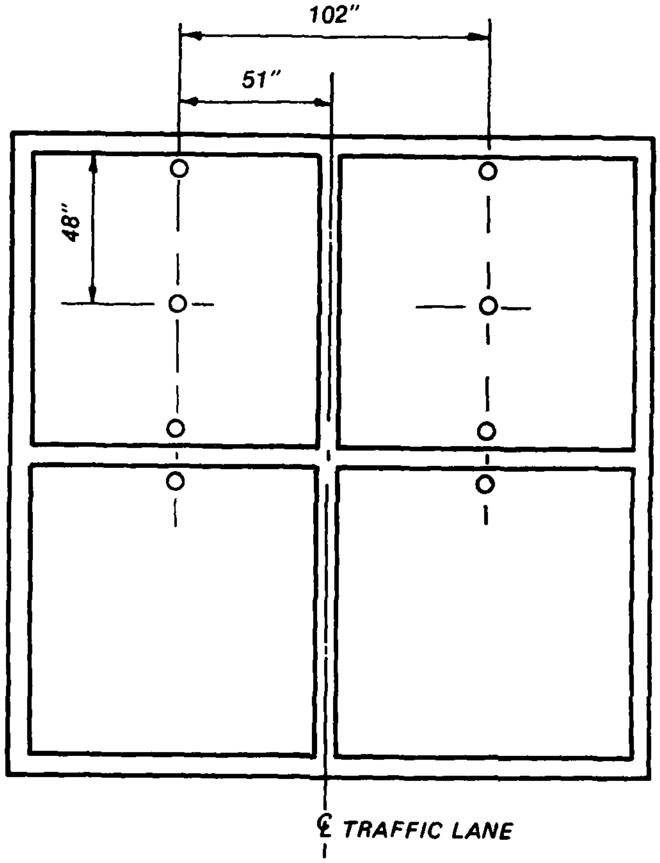


a. TRAFFIC DISTRIBUTION PATTERN FOR THE F-4 LOAD CART



b. TRAFFIC DISTRIBUTION PATTERN FOR THE C-141 LOAD CART

Figure B-5. Traffic Patterns.



O INSTRUMENTATION POINT - AXIAL STRAIN GAGES @ 90° ON BOTTOM OF SLAB AND PRESSURE CELL IN TOP OF SUBGRADE

Figure B-6. Location of Response Instrumentation.

to be available during the test. The objective of the repair will be to fill depressions and restore the surface to an acceptable condition. The repair material will consist of cold-mix asphalt concrete. Periodic measurements should be made (supplemented by continuous visual monitoring) of the trafficked surface. When repairs are necessary, the surface should be swept clean of loose debris, the depressed areas filled in, and the asphaltic material compacted with a vibratory plate compactor. After the surface has been restored, test traffic should be resumed.

6. Information and Data Collection

For each task element, time, equipment, manpower, and material expenditures will be recorded. Data collection shall consist of visual observation of the performance of the slabs during traffic, measurement of changes in surface elevations at the corner and center of each slab, and subgrade stress and slab strain responses. Traffic will be stopped, and data will be taken at 0, 10, 20, 40, 60, 80, 100, and 150 coverages of the F-4 cart and at 0, 10, 20, 40, and 70 coverages of the C-141 cart. [illegible] traffic is terminated at coverage levels below those indicated, data [illegible] will be recorded at that time. Surface elevation data should be obtained [illegible]ng an engineer's level; however, they should also be supplemented by rough[illegible] measurements using the stringline method for comparison with establish[illegible] roughness criteria. Subgrade stress and slab strain data should be obtained [illegible]s of pressure cells and strain gages located as indicated in Figure B-6. [illegible]ypes and sources of pressure cells and strain gages potentially applicable are indicated on Tables B-2 and B-3.

E. TECHNICAL REPORT

A technical report will be prepared, covering design and construction of the test repair area, conduct of the test (including time required for each task), requirements for equipment and manpower, evaluation of the repair effort, and results of traffic tests. Difficulties encountered during the test and recommendations concerning future testing and standardization of repair techniques also will be presented.

TABLE B-2. COMMERCIAL SOURCES OF SOIL PRESSURE CELLS.

Source	Telephone
Terrametrics, Inc. 16027 West 5th Ave. Golden, CO (Carlson Type Soil Stress Meters)	(302)279-7813
Kulite Semiconductor Products, Inc. 1038 Hoyt Ave. Ridgefield, NJ 07657 (Soil Pressure Cell Type 0234, Pressure Ranges 0-15, 0-50, 0-100 psi)	(201)945-3000
Gentran, Inc. 928 Thompson Place Sunnyvale, CA 94086 (Model GT601 or GT621)	(408)245-5501
Sensotec Div. 1400 Holly Ave. Columbus, OH 43212 (Model SA-E Soil Pressure Transducers, Pressure Ranges 0-20, 0-50, 0-600 psi)	(614)294-5436

TABLE B-3. COMMERCIAL SOURCES OF STRAIN GAGES.

Source	Telephone
Micro-Measurements PO Box 306 38905 Chase Rd. Romulus, MI 48174 (4-inch gages, Type EA-06-40 CBY-120 ED-DY-40 CBY-350 2-inch gages, Type EA-06-20 CBW-120 ED-DY-20 CBW-350)	(313)941-3900
BLH Electronics 42 Fourth Ave. Waltham, MA 02154 (Type FSQ2-300-355)	(617)890-6700

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APPENDIX C

PLAN OF TEST, SUBMERGED PRECAST SLAB CRATER REPAIR

(LARGE CRATER FACILITY)

PLAN OF TEST

SUBMERGED PRECAST SLAB CRATER REPAIR

A. OBJECTIVE

The objective of this test is to evaluate procedures and materials to be used in making expedient repairs to a large (estimated 30-foot apparent diameter) exploded crater.

B. SCOPE

This test involves evaluation of all phases of a large crater repair. The repair will include removing crater debris, backfilling the crater with ejecta and pavement debris, cutting the existing pavement to provide an opening suitable for making an acceptable repair, placing of precast concrete slabs on the backfill, and filling the void spaces between and over the precast slab elements with rapid-setting concrete to provide a smooth surface, flush with the surrounding pavement. All phases of the repair procedure will be timed. Structural evaluation of the repair will consist of applying a minimum of 150 coverages of traffic with an F-4 load cart, followed by 70 coverages of a C-141 load cart. Performance of the repair under the applied test traffic will be observed and evaluated.

C. TEST REQUIREMENTS

1. General Description

The test will be conducted at an existing exploded crater site. Repair procedures outlined herein are based on a crater having an apparent diameter of 30 feet and a prepared pavement repair site having a 50-foot by 50-foot square configuration. This repair test will begin with cleaning around the crater site and simultaneous backfilling of the crater with debris and ejecta. Since no external sources of fill aggregate will be involved, the entire crater backfill will consist of fallback, ejecta, and pavement fragments. As soon as enough material has been pushed into the crater to allow maneuvering spaces, work will commence on removal of upheaved pieces of pavement around the crater perimeter. The larger pieces of upheaved pavement will be removed from the site. As soon as practical, cut lines will be marked on the surrounding pavement surface in a square configuration approximately 50 feet by 50 feet. Cutting of the pavement shall be accomplished with equipment specified by the project officer. Broken out pieces of pavement shall be pushed out of the repair site and removed. Final preparation of the backfill shall consist of grading of the material so that the general plane of the surface lies about 12 inches below the elevation of the surrounding pavement. Next, a sand leveling course will be placed on the finished backfill to facilitate leveling of the precast slabs. These units, each 8 feet by 8 feet by 8 inches thick, will be placed on the sand leveling course. Based on a 50-foot by 50-foot opening, 36 precast slabs will be required. After placement of all slabs, the general plane of the top surfaces of the slabs should

be about 2 inches below the surface of the surrounding pavement. A rapid-setting magnesium phosphate cement, Bostik® 276, mixed with coarse aggregate, will be used to finish the repair. The material will be prepared in mobile mixing units at the repair site. The fast-setting concrete will be placed or jetted into voids between slabs and over the surface of the slabs, up to the level of the surrounding pavement, and screeded to form a smooth finished surface. A sketch of the desired repair configuration and slab layout is shown in Figure C-1. After the fast-setting concrete has cured sufficiently, test traffic will be applied on the repair using F-4 and C-141 load carts to evaluate structural adequacy.

2. Resource Requirements

a. Materials

(1) Precast Slabs

Thirty-six precast reinforced concrete slabs will be required for a 50-foot by 50-foot repair site. Design of the precast slabs is shown in Figure C-2. Each slab will have nominal dimensions of 8 feet by 8 feet by 8 inches thick with keyway sides as shown. Each slab will have top and bottom reinforcement and will be equipped with four lifting devices, located as shown. The recommended lifting device is the Dayton Sure-Grip® T-1.

(2) Sand

The leveling course for the precast slabs will be concrete sand. Approximately 30 cubic yards (loose) will be required.

(3) Rapid-Setting Concrete

The material used to fill between slabs and to form the cap will be grout made with Bostik® 276 magnesium phosphate cement mixed with aggregate. The material will be mixed at the site with a mobile concrete mixer. The required quantities of material are 831 units of Bostik R 276 and 16 cubic yards (loose measure) of coarse aggregate. The material will be prepared according to specifications indicated by the manufacturer's literature.

(4) Screed Units

A candidate configuration for a device for screeding the Bostik® concrete is shown as Figure C-3. This device is not commercially available and must be fabricated locally. The device consists of a pedestal unit, spacing shims, a rotation shaft with screed beam attachment unit, and a 24-foot metal-tube screed beam. Four of these devices will be required.

b. Task Elements, Equipment and Manpower

Task elements with time allotments and equipment requirements are indicated in Table C-1. Time lines indicating estimated initiation and

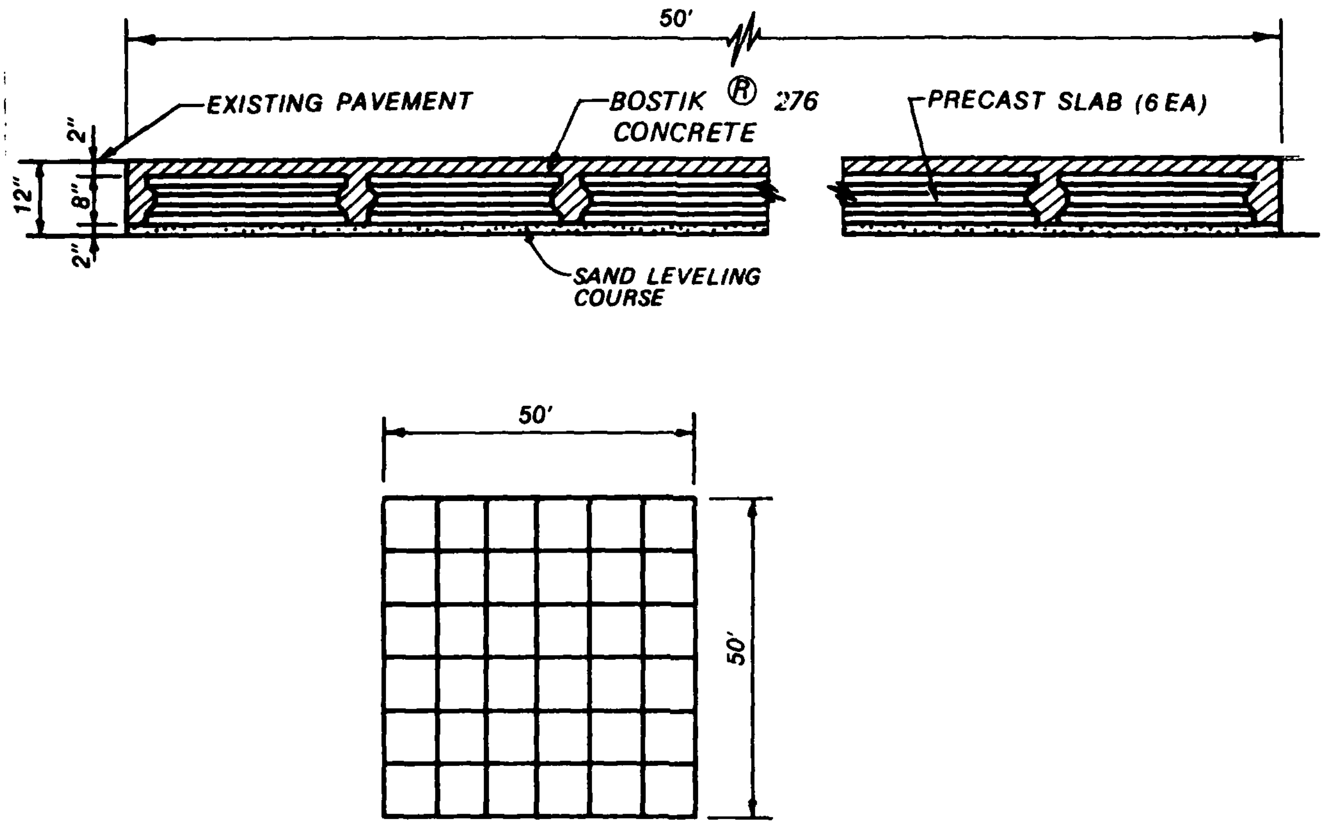


Figure C-1. Repair Concept and Slab Layout.

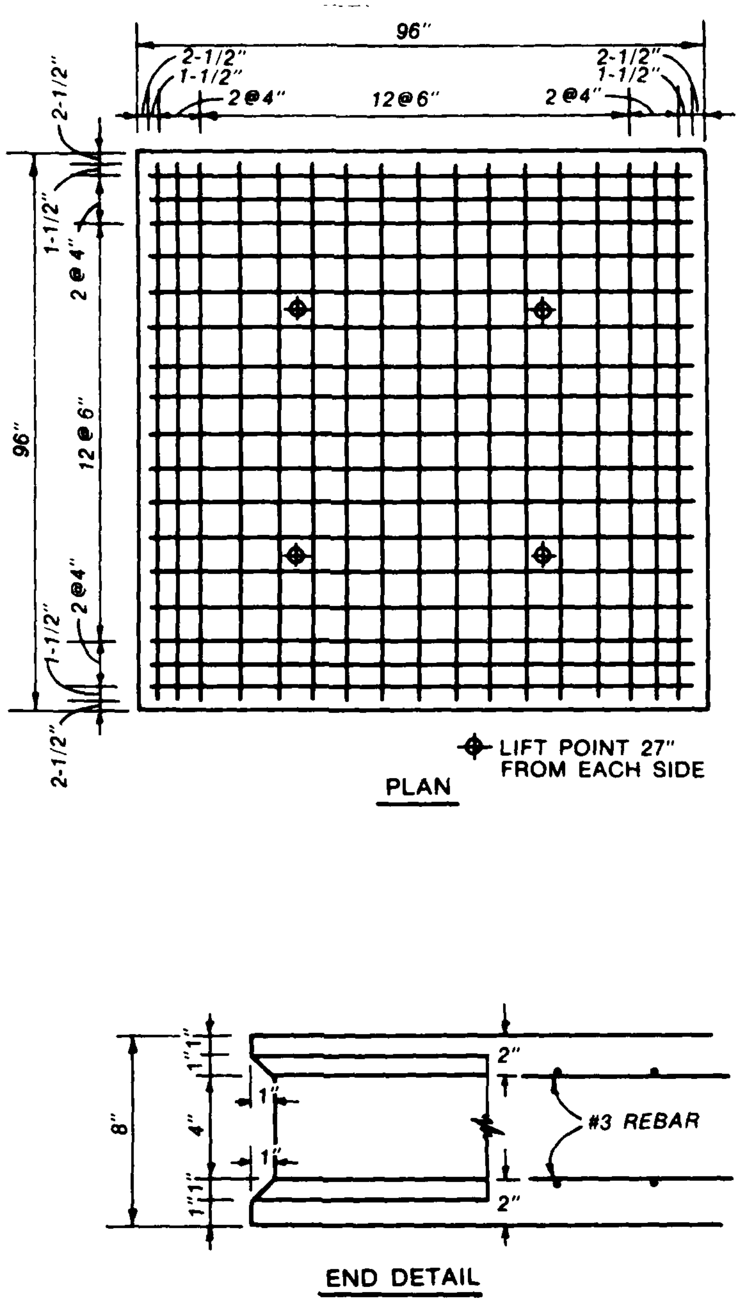


Figure C-2. Slab Design.

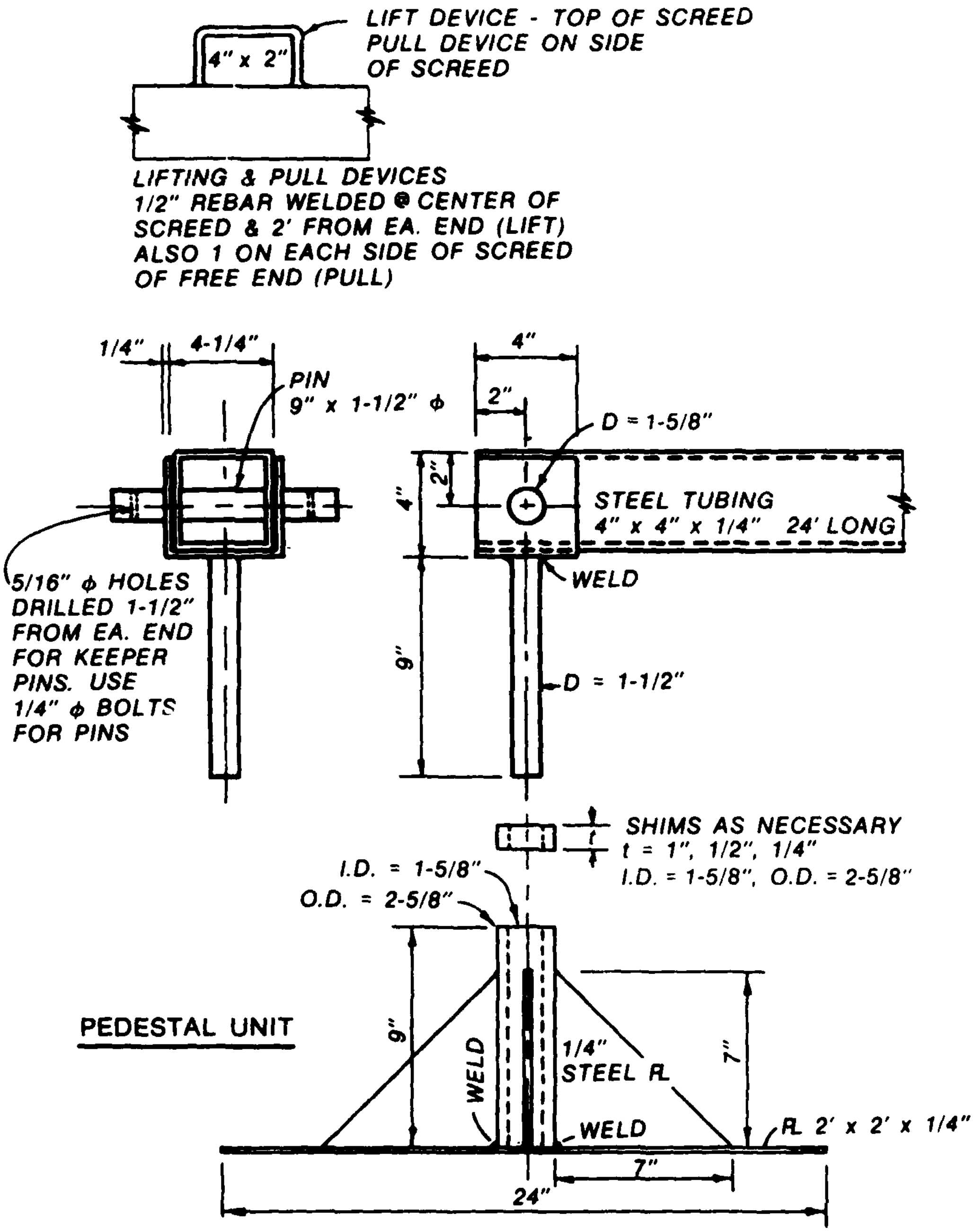


Figure C-3. Screeding Device.

TABLE C-1. TIME AND EQUIPMENT REQUIREMENTS, SUBMERGED SLAB, RAPID-SET CONCRETE, DEBRIS FILL, (50-FOOT BY 50-FOOT REPAIR).

Task	Time (min)	Equipment
Clean Crater	20	2 Dozers/1 Grader/1 Sweeper
Debris in Crater	60	2 Dozers
Remove Upheaval	50	2 Dozers/2 Front-End Loaders
Mark and Cut Pavement	30	Survey Equipment/2 Concrete Saws
Breakout	30	Pneumatic hammer
Remove Broken Pavement	20	2 Dozers/2 Front-End Loaders
Grade Backfill	30	2 Graders
Fine-Aggregate Leveling Course	30	1 Front-End Loader/5 Dump Trucks/Grader/Screeds/Vibratory Plates
Slab Placement	40	2 Forklifts
Rapid Set Concrete	30	4 Mobile Mixers/Screeds
Cure Concrete	60	--
Clean Around Repair	50	1 Sweeper/1 Compr. Dozer/Grader
Maintenance	--	1 Steel Wheeled Roller

completion time for each task are shown in Figure C-4. Based on the scope of the repair test, the repair team should consist of about 40 personnel, including one officer and five NCOs.

c. Cost Estimate

The cost estimates provided below include only those principal expendable items used in the repair test and directly applicable to the repair.

Precast slabs: 35 @ $600 each	$21,600
Concrete sand: 30 cu yd @ $15/cu yd	450
Bostik® 267: 831 units @ $32.26/unit	2,676
Coarse aggregate: 16 cu yd @ $15/cu yd	240
Screed units - 4 @ $250 each	1,000

3. Crater Repair Tasks

a. Initial Clearing

This task marks the beginning of the timed crater repair. In this task, the primary purpose is to clear the area of large debris, and provide adequate working space. This task will be conducted simultaneously with the task, designated "Debris in Crater," since the task of clearing the crater area may be accomplished by pushing ejecta and debris into the crater. For this task, one, and when possible, two, dozers will be used. A sweeper may also be used to clean any small debris.

b. Debris in Crater

For this task, dozers will be used to fill the crater. In the initial stages, except for very large pavement pieces, all debris may be used as fill material. It is anticipated that some compaction of the soil will be accomplished during normal operations of the dozers and, although no special compaction equipment is required, dozer operators should be instructed to ensure that all areas of loose debris are tracked over once or twice with their equipment. As the level of backfill is brought to the surface of the pavement, care should be taken to prevent introducing large pieces of pavement debris that would interfere with final grading of the backfill surface. Enough backfill should be placed so that the ungraded surface is about 11 to 13 inches below the pavement.

c. Remove Upheaval

All upheaved pavement pieces having a change in slope from the undamaged pavement exceeding 5 percent should be removed. A sketch of a suitable straightedge to measure slope of upheaved pavement is shown in Figure C-5.

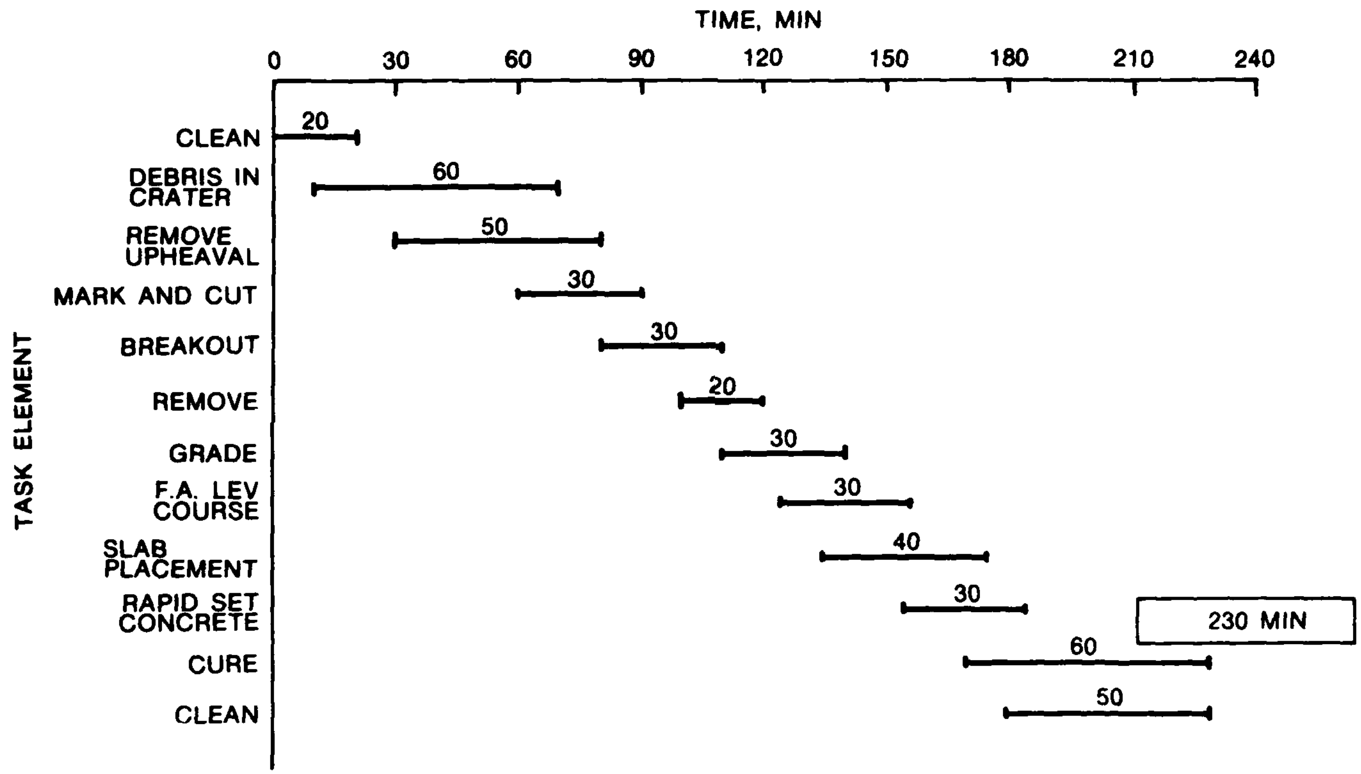


Figure C-4. Task Element Time Allotments.

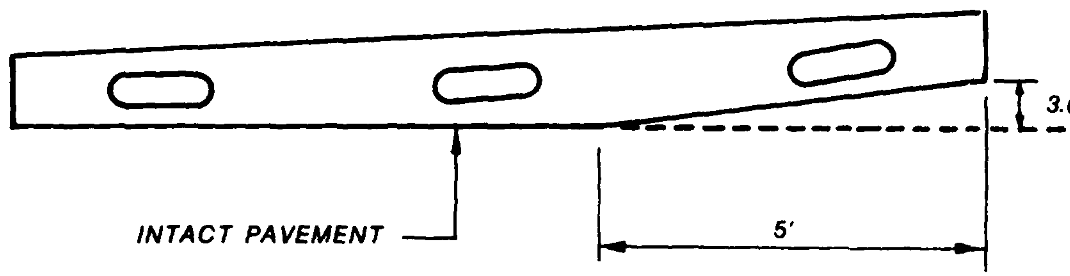


Figure C-5. Suitable 10-Foot Straightedge for Upheaval Measurements.

A dozer should be used to push the broken pieces up and outward from the crater interior, and a bucket loader should be used to transport or push the pavement debris away. This task should commence as soon as enough backfill has been placed in the crater to allow dozer operation without interfering with the backfill operations.

d. Mark and Cut Pavement

Once the general configuration of the crater surface has been defined, it will be necessary to cut the pavement opening to a quadrilateral configuration to conform to the size and shape of the desired grouping of precast slabs to be used in the repair. For this test, a 50-foot by 50-foot opening will be cut. The specific boundaries to be cut will be delineated by the Officer in Charge. Cut lines should be marked clearly with paint or other appropriate marking material. Cutting of the pavement will be initiated as soon as possible. Cutting equipment will be specified by the Project Officer.

e. Breakout and Removal of Pavement

Pavement pieces cut out during the preceding task will be pushed up with a dozer and removed from the site with a bucket loader. Care should be taken to ensure that equipment damage to the underlying base course and subgrade is minimized.

f. Grade Backfill

The backfill material should be graded with a road grader as closely as possible so that the finished surface lies about 12 inches below the surface of the surrounding pavement. Elevation of the graded backfill should be checked regularly during this task by a team of four, using a stringline apparatus similar to that used to check roughness. Due to the greater distances involved, the stringline will tend to sag; therefore, elevation stakes, marked with an engineer's level, should be placed temporarily within the debris backfill area and used as elevation reference points for the stringline measurements.

g. Sand-Leveling Course

Concrete sand should be used for this purpose. The sand should be stockpiled near the repair site. The sand should be loaded into dump trucks with a bucket loader, transported to the site, and dumped directly onto the graded backfill. The sand should be screeded and leveled by hand. The finished sand course should be about 2 inches thick.

h. Slab Placement

To maintain slab alignment and spacing, guide marks should be placed at approximate 8-foot intervals on all sides of the cut. Based on the anticipated repair configuration, maximum spacing between individual slabs and between slabs and the existing pavement will be slightly over 3 inches. Therefore, extra care should be taken to maintain correct alignment. Two forklifts will be required to place slabs. A recommended order of placement of the slabs with the forklifts is indicated in Figure C-6. This placement order provides a means of checking slab alignment using a stringline positioned along the outside edge of each row of slabs. During slab placement, screeding pedestal units should be placed at the locations indicated in Figure C-6. The pedestal units must be placed before the slabs so that the slab corners rest on the base plate to provide stability for the screed units.

i. Rapid-Setting Concrete

Concrete made with Bostik® 276 cement and coarse aggregate, mixed according to manufacturer's specifications, will be used to fill the void spaces between the slabs and to form a grout cap for the surface of the finished repair. Each commercial unit of Bostik® 276 requires 55 pounds of coarse aggregate, and the cement-aggregate mixture is estimated to yield 0.81 cubic feet of concrete. Actual volume of voids and cap is estimated to be 585 cubic feet. Thus, allowing for a 15 percent loss, the recommended volume of mix to be prepared is 673 cubic feet or about 25 cubic yards. Four mobile mixers will be required. The grout should first be jetted or placed in the void spaces between slabs and between slabs and pavement. All of these spaces should be filled before placement of the cap material. The concrete for the cap should be placed,beginning at a corner of the repair opening. Simultaneous placement may be conducted at adjacent corners and the material screeded,using the screeding devices indicated in Figure C-3. With the screed pedestal in place, the shaft unit is fitted into the hollow pipe column atop the base plate, and elevation adjustments can be made using the appropriate shim units. One end of the screed is positioned in the U-shaped unit which is attached atop the shaft and is fixed by means of a horizontal pin device which also allows vertical rotation of the screed. As the concrete is placed,the screed may be rotated horizontally, either manually or by machine, to provide a finished surface on the concrete. As can be seen in Figure C-6, use of four such units allows sufficient overlap to completely traverse the entire 50-foot by 50-foot repair.

j. Curing of Concrete

After the Bostik® concrete cap has been placed, the material requires

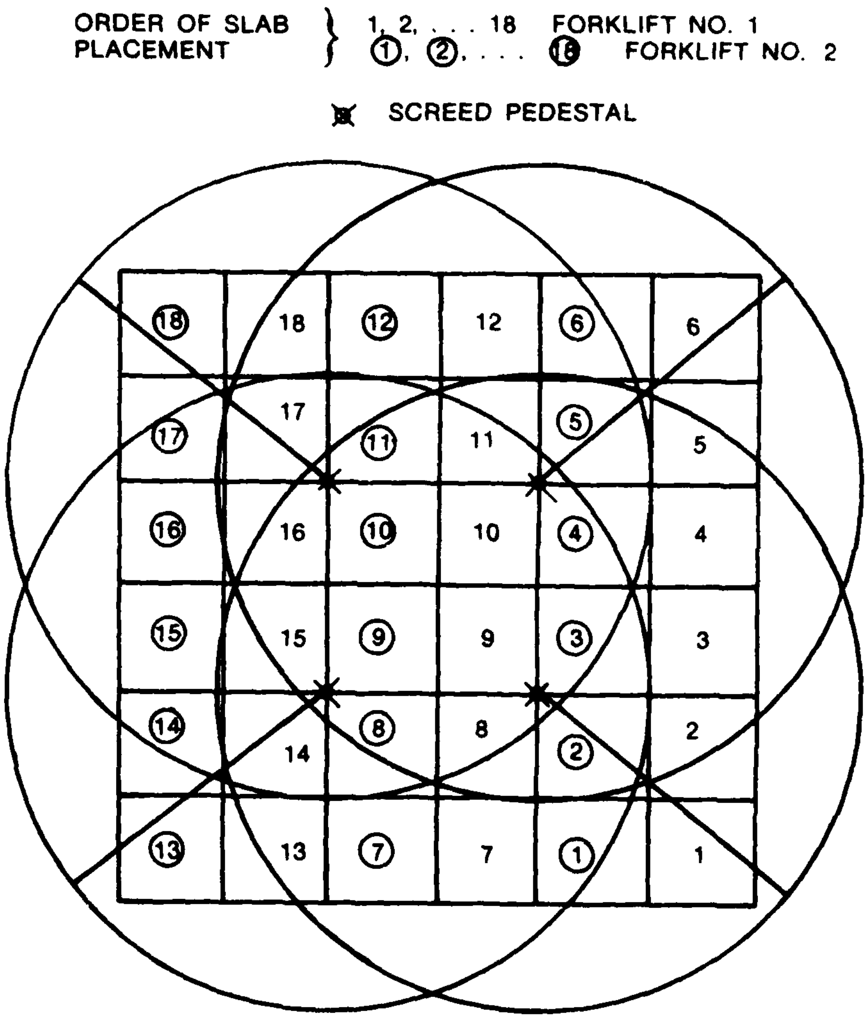


Figure C-6. Slab Placement Order and Screed Pedestal Locations.

about 1 hour to harden sufficiently and reach adequate strength to withstand aircraft traffic. Curing time will vary with temperature and humidity conditions; therefore, the manufacturer's instructions in this area must be followed carefully.

k. Clean Around Crater

When the concrete cap has been completed and is curing, the area around the repair in the direction of anticipated traffic must be cleaned of all debris, pavement fragments, and any material that would present FOD potential. Hand brooms and a mechanical sweeper should be used for this task.

4. Performance Evaluation

a. Test Traffic

(1) General

Test traffic will be applied with the F-4 and C-141 traffic carts. Minimum required traffic levels will be 150 coverages of F-4 and 70 of C-141 coverages.

(2) F-4 Traffic

F-4 traffic will be applied in an approximate normal distribution pattern over a 120-inch-wide lane. Traffic distribution and number of passes are shown in Figure C-7a. A total of 1440 passes will be required for 150 coverages. Position of the traffic lane on the test section will be determined by the Project Officer.

(3) C-141 Traffic

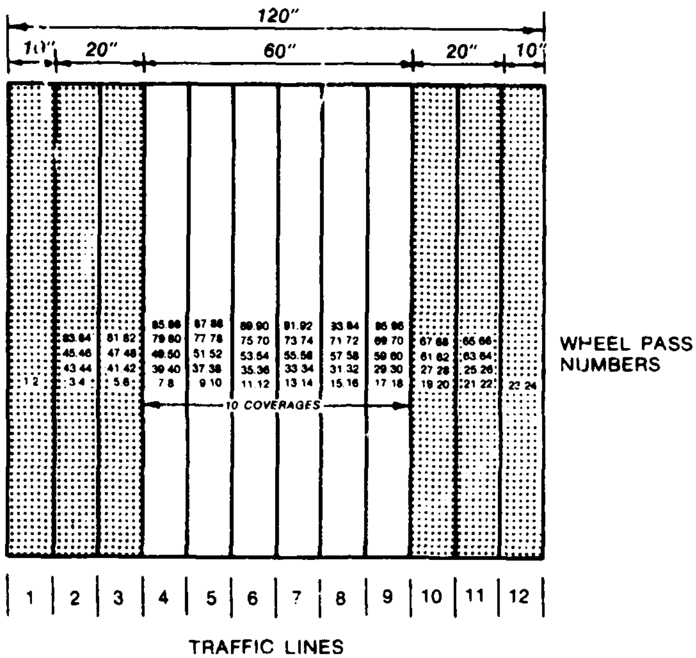
C-141 traffic will be applied in the pattern indicated in Figure C-7b. A total of 420 passes will be required for 70 coverages. Location of the traffic lane will be determined by the Project Officer.

b. Evaluation of Distress

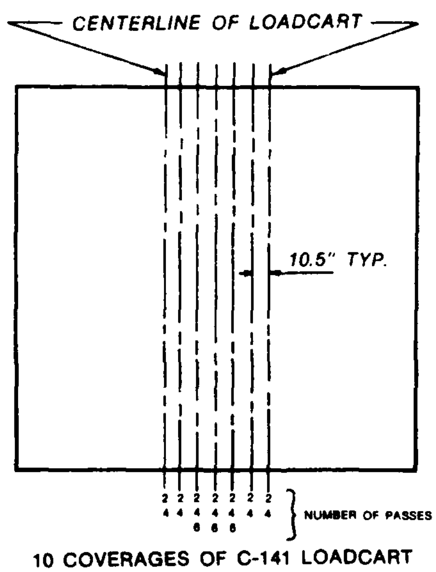
When surface roughness exceeds F-4 Category C criteria as indicated in Rapid Runway Repair Interim Planning Guidance for upheaval and/or sag, the pavement repair will normally be considered failed. In addition, excessive spalling may also constitute failure. While the former condition may be determined by stringline measurement, the latter distress made must be evaluated by the Project Officer. Although a local or general failure condition may develop prior to application of minimum traffic levels, minor maintenance of the damaged area should be attempted if it appears that such procedures prolong the performance life of the repair. However, if it appears that major maintenance will be required the traffic test should be terminated at that point.

5. Maintenance

It is anticipated that this repair will deteriorate under traffic



a. TRAFFIC DISTRIBUTION PATTERN FOR THE F-4 LOAD CART



b. TRAFFIC DISTRIBUTION PATTERN FOR THE C-141 LOAD CART

Figure C-7. Traffic Patterns.

since it is designed to sustain minimum traffic repetitions. Distress such as deformation of the subgrade and cracking and spalling of the submerged slab system may result in large surface deformations exceeding the roughness criteria. Therefore, provision should be made for a repair team whose objective will be to make minor repairs by filling depressions and by restoring the surface to an acceptable condition during the test. Periodic measurements should be made (supplemented by continuous visual monitoring) of the trafficked surface. When repairs are deemed necessary, the surface should be swept clean of loose debris, the depressed areas filled in, and the asphaltic material compacted with a vibratory plate compactor or steel wheeled roller. After the surface has been restored, test traffic should be resumed.

b. Information and Data Collection

For each task element, time, equipment, manpower, and material expenditures will be recorded. Data collection shall consist of visual observation of the performance of the slabs during traffic and measurement of changes in surface elevation across the traffic lane and at the corner and center of each slab in the lane. Data shall be taken at 0, 10, 20, 40, 60, 80, 100, and 150 coverages of the F-4 cart and at 0, 10, 20, 40, and 70 coverages of the C-141 cart. If traffic is terminated at coverage levels below those indicated, data will also be recorded at that time. Surface elevation data should be obtained using an engineer's level; however, they should also be supplemented by roughness measurements, using the stringline method for comparison with established roughness criteria.

D. TECHNICAL REPORT

A technical report covering design and construction of the test repair area, execution of the repair test including time required for each task, requirements for equipment and manpower, evaluation of the repair effort, and results of traffic tests will be prepared. Difficulties encountered during the test and recommendations concerning future testing and standardization of repair techniques will also be presented.

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